DEQ Water Quality Division

State of Oregon
Department of Environmental Quality

Northern Malheur County Groundwater Management Area Trend Analysis Report

December 29, 2003

Table of Contents

DEQ
State of Oregon
Department of Environmental Quality

Water Quality
700 SE Emigrant, #330
Pendleton, OR 97801
Phone: (541) 278-4604
Fax: (541) 278-0168
Contact: Phil Richerson

www.deq.state.or.us

Table of Contents

State of Oregon
Department of Environmental Quality

Water Quality
700 SE Emigrant, #330
Pendleton, OR 97801
Phone: (541) 278-4604
Fax: (541) 278-0168
Contact: Phil Richerson

www.deq.state.or.us

Appendices

List of Tables

List of Figures

Table of Contents

State of Oregon
Department of Environmental Quality

Water Quality
700 SE Emigrant, #330
Pendleton, OR 97801
Phone: (541) 278-4604
Fax: (541) 278-0168
Contact: Phil Richerson

www.deq.state.or.us

Acknowledgments

This report and its companion reports have benefited from both formal comments received from reviewers of draft versions of this document and from informal conversations regarding statistical methods, hydrogeology, and local agriculture. Valuable input was received from the Oregon Department of Environmental Quality (Curtis Cude, Bill Mason, Barbara Sellars, Karla Urbanowicz, Mike Wiltsey, and Mitch Wolgamott), the Oregon Department of Agriculture (Erick Burns), the United States Geological Survey (Ed Gilroy and Dennis Helsel), the USDA Natural Resources Conservation Service (Jason Outlaw), the City of New York Department of Environmental Protection (David Smith), and the Northern Malheur County Groundwater Management Committee (Clint Shock, Jim Nakano, Al Murrey, Ken Rawson, Lance Phillips, Ron Jones, Ken Diebel, Ray Huff, and Kathy Pratt).

State of Oregon
Department of Environmental Quality

Eastern Region Water Quality Program
700 SE Emigrant, #330
Pendleton, OR 97801
Phone: (541) 278-4604
Fax: (541) 278-0168
Contact: Phil Richerson

www.deq.state.or.us

Executive Summary

Introduction

The Northern Malheur County Groundwater Management Area (NMC GWMA) was declared in 1989 after widespread groundwater nitrate contamination was identified that had resulted primarily from nonpoint source activities. Oregon DEQ and a citizen's advisory committee created an Action Plan for restoring the groundwater nitrate concentrations to acceptable levels. The Action Plan identifies specific "measures" to gauge the success of changes in the area. The three measures that relate to nitrate concentrations and trends are the subject of this report.

This report is a companion to the "Northern Malheur County Groundwater Management Area Best Management Practice Implementation Report" which describes the positive changes that have occurred due to the efforts of local growers, agricultural equipment suppliers, educational institutions, and governmental agencies. These two reports are summarized in a third document titled "Evaluation of Northern Malheur County Groundwater Management Area Action Plan Success".

State of Oregon
Department of Environmental Quality

Eastern Region Water Quality Program
700 SE Emigrant, #330
Pendleton, OR 97801
Phone: (541) 278-4604
Fax: (541) 278-0168
Contact: Phil Richerson

www.deq.state.or.us

Purpose of the Study

The purpose of this study is to determine, through an analysis of NMC GWMA water quality data, if the three water quality measures of Action Plan success have been met. As part of this analysis, the entire database was evaluated using several different techniques to determine what data should be included in the analysis and how the analysis should be conducted.

Previous Trend Analyses

Previous trend analyses conducted by DEQ and others are summarized. Observations and recommendations made in previous studies were taken into consideration in conducting the current study.

Methods

Water quality was evaluated by aquifer, at individual wells, as area-wide trends, and along specific groundwater flow paths. Various trend analysis techniques were used to evaluate potential trends.

Conclusions

The major conclusions drawn from this study are:

1) The three measures of Action Plan success based on groundwater quality values have not yet been met. These measures of success were overly optimistic; it is clear that a longer time frame will be required for these measures of success to be met, and
2) The area-wide nitrate trend appears to be no longer increasing. This conclusion is based on four estimates of the area-wide nitrate trend that suggest it is either flat or slightly declining (up to 0.3 parts per million (ppm) decline per year). This conclusion is not definitive because the nitrate trends at individual wells were mixed (i.e., they included increasing, decreasing, flat, and statistically insignificant[1] trends).

Some of the supplemental conclusions drawn from this study include:

- The Seasonal Kendall procedure should be used exclusively to quantify water quality trends in the NMC GWMA.
- The 10 ppm nitrate drinking water standard was exceeded at least once at 27 of the 38 wells while the average nitrate concentration exceeded the drinking water standard at 20 of the 38 wells.

[1] Because a well has a statistically insignificant trend does not mean that the concentrations observed at the well are insignificant or unworthy of attention. Instead, this means that a straight line could not be drawn through the data with a high degree of confidence.

Executive Summary

- Nitrate data generated using the electrode probe method should not be used in this or future trend analyses.
- Geographic location has a strong influence on general water quality, nitrate concentrations, and nitrate trends.
- The area-wide trend of the pesticide Dacthal and its breakdown products (termed DCPA & metabolites) appears to be decreasing. This conclusion is based on four estimates of the area-wide DCPA & metabolites trend that suggest it is decreasing at a rate of 0.23 to 5.0 ppb per year. This conclusion is not definitive because the DCPA & metabolites trends at individual locations are mixed (i.e., 45% decreasing, 40% statistically insignificant, 12.5% increasing, and 2.5% flat). However, because 88% of trends are either decreasing, flat, or statistically insignificant, an overall DCPA & metabolites trend may still provide useful information.
- The health advisory level for DCPA & metabolites was 4000 parts per billion (ppb) at the time of Action Plan adoption but has since been changed to 70 ppb. The current health advisory level was exceeded at least once at 19 of the 38 wells. The average DCPA & metabolites concentration exceeded the health advisory level at 9 of the 38 wells.
- Because this analysis was conducted approximately four years after DCPA use essentially ended, the increasing DCPA & metabolites trends in wells located near the end of groundwater flow paths illustrates the need for a longer time frame to flush the aquifer.
- The travel time required for DCPA & metabolites to completely flush through the system will provide useful information in evaluating nitrate transport through the system.

State of Oregon
Department of Environmental Quality

Eastern Region Water Quality Program
700 SE Emigrant, #330
Pendleton, OR 97801
Phone: (541) 278-4604
Fax: (541) 278-0168
Contact: Phil Richerson

www.deq.state.or.us

Recommendations

Based on the conclusions presented in this report, the following recommendations are made.

Groundwater Management Committee and Malheur County SWCD

- Re-evaluate and fine tune BMP implementation in the Owyhee River area and near specific well locations with increasing nitrate trends and/or elevated nitrate concentrations.
- As appropriate and as resources allow, evaluate the possibility of point source contributions in the vicinity of wells with increasing nitrate trends.
- As available and appropriate, provide financial and technical support to assist in the continued research, documentation, and implementation of appropriate BMPs in the GWMA as well as projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

Groundwater Management Committee and DEQ with support from Federal, State, and County Agencies associated with this project

- Amend the Action Plan to allow the use of the Seasonal Kendall method for the evaluation of water quality trends rather than requiring the use of the ordinary least squares method.

DEQ

- Continue the existing sampling plan (i.e., sample the 38 wells and 2 surface water bodies every other month) to maintain the water quality database.
- Perform another formal trend analysis of nitrate concentrations in 2005 using cadmium reduction nitrate data collected through December 2004.
- As available and appropriate, provide financial and technical support to assist in the continued research and implementation of appropriate BMPs in the GWMA as well as projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

Registered Professional Geologist Seal

In accordance with Oregon Revised Statutes Chapter 672.505 to 672.705, specifically ORS 672.605 which states:

"All drawings, reports, or other geologic papers or documents, involving geologic work as defined in ORS 672.505 to 672.705 which shall have been prepared or approved by a registered geologist or a subordinate employee under the direction of a registered geologist for the use of or for delivery to any person or for public record within this state shall be signed by the registered geologist and impressed with the seal or the seal of a nonresident practicing under the provisions of ORS 672.505 to 672.705, either of which shall indicate responsibility for them.",

I hereby acknowledge that the document cited below was prepared by me.

Document Title: Northern Malheur County
Groundwater Management Area Trend Analysis Report

Document Author(s): Phil M. Richerson

Document Date: December 29, 2003

Name of Oregon RPG: Phil M. Richerson (G1906)

Signature of Oregon RPG: Phil Richerson

Date of Seal: 12/29/03

1.0 INTRODUCTION

The Northern Malheur County Groundwater Management Area (NMC GWMA) was declared in 1989 after widespread groundwater nitrate contamination was identified that had resulted primarily from nonpoint source activities. Oregon DEQ and a citizen's advisory committee created an Action Plan for restoring the groundwater nitrate concentrations to acceptable levels. The Action Plan identifies specific "measures" to gauge the success of changes in the area. The three measures that relate to nitrate concentrations and trends are the subject of this report.

This report is a companion to the December 2003 "Northern Malheur County Groundwater Management Area Best Management Practice Implementation Report" which describes the positive changes that have occurred due to the efforts of local growers, agricultural equipment suppliers, educational institutions, and governmental agencies. These two reports are summarized in a third document titled "Evaluation of Northern Malheur County Groundwater Management Area Action Plan Success" dated December 2003.

This section of the report provides information on the establishment of the Northern Malheur County Groundwater Management Area, the purpose of this trend analysis study, and ways to measure success of the Northern Malheur County Groundwater Management Action Plan.

1.1 Establishment of Northern Malheur County Groundwater Management Area

Oregon's Groundwater Protection Act of 1989 requires the Oregon Department of Environmental Quality (DEQ) to declare a Groundwater Management Area (GWMA) if area-wide groundwater contamination, caused primarily by nonpoint source pollution, exceeds certain trigger levels.

Nonpoint source pollution of groundwater results from contaminants coming from diffuse land use practices, rather than from discrete sources such as a pipe or ditch. The contaminants of nonpoint source pollution can be the same as from point source pollution, and can include sediment, nutrients, pesticides, metals, and petroleum products. The sources of nonpoint source pollution can include construction sites, agricultural areas, forests, stream banks, roads, and residential areas.

The Groundwater Protection Act also requires the establishment of a local Groundwater Management Area Committee comprised of affected and interested parties. The committee works with and advises the state agencies that are required to develop an action plan that will reduce groundwater contamination in the area.

The Northern Malheur County GWMA was declared in 1989 after groundwater contamination was identified in an 115,000-acre area in the northeastern portion of the county where land use is dominated by agriculture. The GWMA boundary starts at the mouths of the Malheur and Owyhee Rivers where they converge with the Snake River and extend to the uppermost irrigation canals. The approximate location of the Northern Malheur County GWMA is indicated in Figure 1-1. The locations of the 38 wells and 2 surface water sample locations used to collect water quality data for this trend analysis are indicated in Figure 1-2. The selection of the wells was based primarily on an attempt to obtain good geographical coverage of the area while using wells with good well logs and accommodating owners. However, the uneven distribution of wells throughout the GWMA may over-represent some areas while under-representing other areas.

Groundwater samples from private water wells identified nitrate contamination and the presence of the pesticide dacthal[2] and its breakdown products (hereafter known as DCPA & metabolites[3]). Traditional fertilizer and

[2] Dacthal is a trade name for dimethyl tetrachloroterephthalate (DCPA). Dacthal is the term used in the Action Plan.
[3] The analytical method used consistently throughout this sampling program does not distinguish between DCPA and its metabolites (i.e., one value representing the sum of the parent and daughter products is reported). However, when a different analytical technique was occasionally used during the sampling program, it was determined that DCPA was not detected but its metabolite(s) were detected. Therefore, concentrations reported as "DCPA & metabolites" are actually representative of only the metabolite(s).

agricultural chemical application practices are believed to be the main source of the contamination. Other possible sources of nitrate identified in the GWMA include residential lawn care, on-site sewage systems (i.e., septic tanks), confined animal feed lot operations, and food processing facilities.

Sampling confirmed that most of the contaminated groundwater is present in the shallow alluvial sand and gravel aquifer which receives a large proportion of its recharge from canal leakage and irrigation water. Therefore, the shallow aquifer is the focus of efforts to restore groundwater quality in Northern Malheur County.

1.2 Northern Malheur County Groundwater Management Area Action Plan

The Northern Malheur County Groundwater Management Action Plan, hereafter referred to as the Action Plan (Malheur County Groundwater Management Committee, 1991) was developed to reduce existing contamination and prevent further contamination of groundwater in the GWMA. The Northern Malheur County Groundwater Management Committee, the Technical Advisory Subcommittee, and representatives from the DEQ, the Oregon Department of Agriculture (ODA), the Oregon Water Resources Department (OWRD), the Oregon Department of Human Services (formerly known as the Oregon Health Division (OHD)), and Oregon State University (OSU) conducted an 18-month effort ending with approval of an Action Plan focused on reducing groundwater contamination in the GWMA. The Action Plan is available online at http://www.deq.state.or.us/wq/groundwa/NMalheurGWMgmtArea.htm.

The Action Plan includes detailed information on water quality, identification of contaminant sources, and recommendations for implementation of Best Management Practices (BMPs) to improve groundwater quality. This approach allows farmers to customize a sequence or system of available BMPs to their individual farm operations. The Committee chose to implement the Action Plan on a voluntary basis recognizing that individuals, businesses, organizations, and governments will, if given adequate information and encouragement, take positive actions and adopt or modify practices and activities to reduce contaminant loading to groundwater.

As part of implementation of the Action plan, a network of 38 wells (mostly private drinking water and irrigation wells) and 2 surface water bodies is sampled every other month for analysis of nitrate and DCPA & metabolites. Approximately once a year, these wells and surface water bodies are sampled for a larger list of analytes including major ions, metals, and additional pesticides. These data provide the basis for this study.

1.3 Purpose of This Study

The purpose of this study is to determine, through an analysis of NMC GWMA water quality data, if the three water quality measures of Action Plan success have been met. As part of this analysis, multiple data sets were evaluated using several different techniques to determine what data should be included in the analysis and how the analysis should be conducted. Results of the evaluation are presented in Appendix A.

1.4 Measures of Action Plan Success

The Action Plan specifies four specific ways to gauge success. Three of these are related to water quality concentrations or trends (i.e., changes in groundwater quality over time) in response to adoption of BMPs. The fourth measure of success involves the adoption of BMPs (i.e., "other indicators of progress"). These measures of success are reiterated below.

The Action Plan will be considered successful if:

(1) A trend analysis indicates, at a 75% confidence level, that the level of the nitrate monitoring data for the entire management area is 7 mg/l; or
(2) A trend analysis indicates, at the 80% confidence level, that nitrate levels will reach 7 mg/l by July 1, 2000; or
(3) A statistically significant downward trend can be demonstrated at the 80% confidence level; or

(4) Other indicators show progress toward this goal. Other indicators of progress may include but are not limited to the following:
- number of producers adopting farm plans;
- an increase in utilization of soil testing to improve fertilization practices;
- an increase in efficiency of nitrogen fertilizer application: timing, placement, form, & rate;
- an increase in irrigation efficiency, reducing deep percolation;
- a vadose zone drilling project demonstrating decrease in concentrations of nitrate;
- number of water quality practices being applied; and
- Ontario Hydrologic Unit Area reports and evaluations of progress and effectiveness.

The first three measures of Action Plan success (i.e., those related to water quality trends) are discussed in this report. The fourth measure of success (i.e., the other indicators of progress) is discussed in companion document titled "Northern Malheur County Groundwater Management Area Best Management Practice Implementation Report" dated December 2003. The success of the Action Plan as a whole is discussed in the document titled "Evaluation of Northern Malheur County Groundwater Management Area Action Plan Success" dated December 2003.

2.0 PRINCIPLES OF TREND ANALYSIS

This section provides information on the principles of conducting statistical trend analyses on groundwater quality data collected over an extended period of time, and on the types of statistical tests that area appropriate for this evaluation.

2.1 Types of Trends

A primary goal of many water quality monitoring projects is to collect and analyze data so that changes in water quality over time (i.e., trends) can be detected. These trends can be related to both point sources and nonpoint sources; and are often related to changes in land use practices or patterns.

The two basic types of trends that can be statistically analyzed are step and monotonic. Step trends include either a sudden increase or decrease in concentration resulting from a sudden change in the primary activity controlling water quality. An example of a step trend would be a sudden increase in stream temperature downstream of a new surface water discharge. Monotonic trends are generally gradual changes that are either increasing or decreasing with no reversal of direction. An example of a monotonic trend would be the gradual decrease of groundwater nitrate concentrations as BMPs are implemented in an agricultural area.

Both step and monotonic trends can be increasing or decreasing. In addition, cycles (such as seasonal precipitation changes, tides, production schedules of industry, etc.) can be superimposed on trends. These cycles are not trends because they do not represent long-term changes.

For the purposes of this study, monotonic trend analysis techniques are believed to be most appropriate. This is largely due to the slow nature of contaminant transport in a groundwater system resulting in a relatively gradual change in groundwater quality in spite of the relatively rapid implementation of BMPs. In short, groundwater responds slowly; even to rapid changes at land surface.

2.2 Effects of Natural Fluctuations and Human Activity

It is possible for an apparent trend in water quality to be caused or masked by meteorological conditions such as precipitation cycles. It is also possible for an apparent trend in water quality to be caused or masked by human activities such as the production schedules of industry. Therefore, it is sometimes necessary to use special trending techniques to reduce the effect of outside influence (i.e., exogenous factors) on the data being examined. The purpose of adjusting the data for an exogenous variable is to reduce the background (i.e., “noise”) so that the detection of trends (i.e., “signal”) is more powerful.

For studies involving stream water quality trends, corrections are often needed to account for the flow/concentration relationship. In this study, the primary outside influence on the data is believed to be the seasonal changes in water quality caused by the irrigation season. Therefore, an evaluation of the seasonal component of water quality changes was conducted.

Measurements taken in close proximity over time are likely to be related to each other (known as autocorrelation or serial correlation), but most statistical tests require uncorrelated data (Gilbert, 1987). However, there are methods to detect serial correlation (e.g., the Durbin-Watson test). The Durbin-Watson statistic is a technique used to detect serial correlation in the residuals of a regression equation. The technique compares the residual from one time period with the residual from the previous time period, and computes a statistic that measures the significance of the correlation between these successive comparisons. The test statistic ranges from 0 to 4 and depends on the size of the data set, the number of explanatory variables in the regression equation, and the confidence level. A value near 2 indicates no serial correlation. A value near 0 indicates positive serial correlation. A value near 4 indicates negative serial correlation. There are also statistical techniques that have been developed which can account for serial correlation once it has been detected. One such technique is the Seasonal Kendall test with correction for correlation. For more information on this technique, the reader is referred to Hirsch, et al., 1984.

Loftis et.al., (1991) concludes that the distinction between serial correlation and trend is scale dependent. In other words, the distinction between serial correlation and trend is an artifact of the mathematical model used to evaluate the data as well as the time scale over which it is applied. For example, nitrate concentrations that are essentially constant over a long time (e.g., a flat trend) may contain short-term patterns which would be important from a management standpoint (e.g., decreasing trend within first half of observations). Loftis et. al., (1991) also notes that it is commonly, and probably appropriately, assumed that the scale of interest of a trend analysis is equal to the length of record (i.e., trend tests are applied to the entire record). Loftis et. al., (1991) further concludes that there is no "correct" way to approach water quality data analysis in terms of accounting for scale dependence but serial correlation can be ignored if the scale of interest is confined to the period of record.

It is clear that in order to detect or assess trends it is necessary that the data be collected at a given location using consistent collection and measurement techniques on a regular schedule and over a substantial number of years (Hirsch, et al., 1982). A change of analytical laboratories or of sampling and/or analytical procedures may occur during a long-term study. Unfortunately, this may cause a shift in the mean or in the variance of the measured values. Such shifts could be incorrectly attributed to changes in the underlying natural or man-induced processes generating the pollution (Gilbert, 1987). This issue affected this study in that two different analytical techniques (i.e., electrode method and cadmium reduction method) were used to analyze samples for nitrate. A comparison of trends produced by the two methods and analyzing various combinations of the data using multiple techniques is provided in Appendix A.

2.3 Factors Complicating Trend Analysis

In order to conduct a statistically meaningful trend analysis of groundwater quality data, important assumptions regarding the data distribution (e.g., normal distribution) must be met for the chosen technique. In addition, several factors complicate the detection of groundwater quality trends. These complicating factors include seasonality, autocorrelation, missing values, outliers, and measurements near a detection limit. These complicating factors are discussed in more detail in Sections 2.4 and 2.5 of this report. Furthermore, results of the trend analysis must be examined for reasonableness (i.e., a "reality check").

For example, a small but true water quality trend may not be detected in a data set with a high degree of seasonality by a technique that does not account for seasonality. As another example, if a series of measurements is reported at the detection limit, deviations from the trend line will not be normally distributed and the standard error of the least squares trend estimator will no longer apply. In many cases, outliers in the data will produce biased estimates of the least squares estimated slope itself (Gibbons, 1994).

For a steeply sloped trend, relatively few data points are necessary for the calculated values to be statistically significant. However, for a very small slope, a great deal more data may be required before the value can be confirmed as significant. Two possible consequences can occur as a result of this concept. First, two equally real trends in water quality may exist but only one will be found statistically significant because it will have a somewhat longer period of data collection. Second, an examination of an extensive data set may find a statistically significant trend that is so small as to be physically insignificant or meaningless (e.g., 0.001 mg/l/yr).

2.4 Parametric versus Nonparametric Techniques

A parametric technique is one whose validity depends upon the data being drawn from a specific known distribution (e.g., normal or log-normal). Parametric methods discussed in this report include simple least squares regression (linear regression), seasonal least squares regression, and sine/cosine seasonal least squares regression. A nonparametric (or distribution-free) technique is one whose validity does not depend upon the data being drawn from a specific distribution. The magnitude of data is ignored in favor of the relative values or ranks. Nonparametric techniques discussed in this report include the Mann-Kendall, Spearman's rho, Seasonal Kendall without correction for correlation, and the Seasonal Kendall with correction for correlation.

If the requirements of a regression equation were known to be true (i.e., a strictly linear relationship and normally distributed residuals), then fully parametric regression would be optimal (i.e., most powerful and lowest error variance for the slope). If the actual situation departs, even to a small extent, from these assumptions then a non-parametric (i.e., Mann-Kendall) procedure will perform either as well or better (Helsel & Hirsch, 1992). If one knows that the data to be examined for trends are normal and nonseasonal, then linear regression is clearly the best. If one knows that the data are normal but seasonal, then seasonal regression may be best (depending on the magnitude of the seasonality) (Hirsch, et al., 1982).

Nonparametric procedures are always nearly as powerful as regression, and the failure to edit out or correctly transform a small percentage of outlying data will not have a substantial effect on the results (Helsel & Hirsch, 1992). The advantage of non-parametric procedures is that there are very few underlying assumptions about the structure of the data making them robust against departures from normality. In addition, the use of ranks rather than actual values makes them insensitive to outliers, moderate levels of non-detected values, and missing values.

Given that departure from normality and the presence of seasonality are common features of water quality data, coupled with the rather small loss of power associated with using the Seasonal Kendall test where the linear regression test would be most powerful, the use of the Seasonal Kendall test is recommended as an exploratory test for trend by some researchers.

2.5 Monotonic Trend Analysis Techniques

There are several types of monotonic trend analysis techniques available for use. Not all techniques are appropriate for every data set. A trend can be visually examined by plotting the observed data versus time. However, a statistical test is required to analyze the trend. If plots of the data versus time suggest a simple linear increase or decrease over time, a linear regression of the variable against time may be fit to the data. A test can be used to evaluate if the slope is different than zero. This test can be misleading if seasonal cycles are present, the data are not normally distributed, and/or the data are serially correlated (Gilbert, 1987). In fact, the results may indicate a significant slope when the true slope actually is zero (Hirsch, et al., 1982).

The Mann-Kendall test is a nonparametric procedure particularly useful in water quality evaluations since missing values are allowed and the data need not conform to any particular distribution. Also, data reported as below a detection limit can be used by assigning them a common value that is smaller than the smallest measured value in the data set. This approach is valid because the Mann-Kendall test uses only the relative magnitudes of the data rather than their measured values (Gilbert, 1987). The Mann-Kendall test analyzes the sign difference between later-measured data and earlier-measured data. Each later-measured datum is compared to all data measured earlier. An increasing trend is identified if later-measured values tend to be larger than earlier-measured values. Conversely, a decreasing trend is identified if later-measured values tend to be smaller than earlier-measured values.

If a linear trend is present, the true slope may be estimated by linear regression methods. However, the regression-calculated slope can differ greatly from the true slope if there are gross data errors or outliers in the data. Sen's slope estimator is not greatly affected by gross data error or outliers, and it can be computed when data are missing. Sen's slope estimator is closely related to the Mann-Kendall statistic in that all possible slopes are calculated between all possible data pairs and the resulting median slope is the Sen slope. The Sen's slope estimator is used to estimate the slope for the Mann-Kendall test.

If seasonal cycles are present in the data, tests for trend that remove these cycles or are not affected by them should be used (Gilbert, 1987). The seasonal least squares regression technique and the sine/cosine seasonal least squares technique remove seasonality (deseasonalize the data) while the Seasonal Kendall test accounts for seasonality in the evaluation. The Seasonal Kendall test may be used even though there are missing, tied, or non-detected values. As mentioned previously, the validity of the test does not depend on the data being normally distributed.

Hirsch, et.al, (1982) evaluated the performance of linear regression applied to deseasonalized data. This procedure (called seasonal regression) gave test results that performed well when seasonality was present, the data were normally distributed, and serial correlation was absent. However, they suggest the Seasonal Kendall test is preferred to the simple or seasonal regression tests when data are skewed, cyclic, and serially correlated. When a time series contains any non-detected values, then parametric methods of trend detection become unusable. These non-detected values present no difficulty for nonparametric methods such as the Seasonal Kendall test because nonparametric tests require making comparisons of values to determine which is the larger. The non-detected data can all be considered to be smaller than any numerical value equal to or greater than the detection limit and tied with any other non-detected value. In cases where the detection limit has changed over time as more sensitive instruments are developed, it is necessary to take all data reported below the highest detection limit (including those reported as less than any lower detection limit) and consider them all to be tied at the highest detection limit (Hirsch, et al., 1982).

A variation of Sen's slope estimator called the Seasonal Kendall slope estimator (or the Seasonal Sen Slope estimator) is used to calculate the slope for the Seasonal Kendall test. The difference is that all possible slopes within each season are calculated with the median slope being the Seasonal Kendall slope.

A variation of the Seasonal Kendall technique is also available to account for serial correlation if it is present. However, the power to detect a trend is reduced when this technique is used.

EPA (1997) recommends the following. Use the Seasonal Kendall test for hypothesis testing when testing for monotonic trends. Linear regression might also be used but is generally discouraged. If the data do not have seasonal cycles, the Mann-Kendall test could be used. The Seasonal Kendall slope estimator is recommended when estimating the magnitude of monotonic trends when seasonality is present and the Sen slope estimator when seasonality is not present.

Table 2-1 presents a comparison of the seven monotonic trend analysis techniques used in this study. See Appendix A for a comparison of results from these techniques. Some of the assumptions regarding data distribution and technique applicability, as well as the complicating issues, are identified. Table 2-1 is not intended to be a comprehensive evaluation of these techniques. Rather, it is intended to provide the reader with some basis to distinguish the techniques. Readers interested in more details on how these techniques are used in water quality evaluations are encouraged to read Gilbert (1987) and Helsel and Hirsch (1992).

Appendix B contains graphs with nitrate and DCPA & metabolites concentrations plotted versus time for each of the 40 monitoring locations in the GWMA (pages B-1 through B-40). The Seasonal Kendall trend line on these graphs is hinged at median time and median concentration values. The trend line is rotated to coincide with the Sen slope. Appendix B also contains a table with DEQ and OWRD well designations (page B-41).

2.6 Multiple Observations at Multiple Locations

When evaluating multiple sample locations with multiple observations, it may be desirable to express the results as an overall regional summary statement across all sampling locations. However, there must be consistency in behavioral characteristics across sites over time in order for a single summary statement to be valid across all sampling locations. If the stations exhibit approximately steady trends in the same direction (upward or downward), with comparable slopes, then a single summary statement across stations is valid (EPA, 2000). Gilbert (1987) stated this idea slightly differently as "when data are collected at several stations within a region or basin, there may be interest in making a basin-wide statement about trends. A general statement about the presence or absence of monotonic trends will be meaningful if the trends at all stations are in the same direction – that is, all upward or all downward."

One method of evaluating whether there is a general trend evident throughout an entire region is by performing the "Regional Kendall test" (Practical Stats Internet Site, 2000). This is done by altering the Seasonal Kendall test so that instead of testing data from all sample locations collected from a specific time interval (e.g., a particular month), data from individual sample locations collected from specific time intervals are tested. In both the Seasonal Kendall test and the Regional Kendall test, data blocks are tested individually, and then combined into one overall test result. To conduct a Regional Kendall test, blocks of data are constructed of results from a specific location during the same time period. For example, consider an example of a data set consisting of 40 wells sampled every other month for 10 years. A block of data could consist of nitrate values for a particular well sampled in January of each year (i.e., 10 data points). The test statistic is computed for each location, and then summed for all locations. The overall test statistic is divided by its standard error, a continuity correction is applied and then compared to a table of the normal distribution. The result declares whether or not there is a significant up or down trend over time for the entire region. Note that if there is an increasing trend at one location and a decreasing trend at another, they will tend to cancel one another and no overall trend may be found, even if the individual tests are significant (Practical Stats Internet Site, 2000).

Another method of evaluating whether there is a general trend evident throughout an entire region is by performing a global trend test (van Belle and Hughes, 1984). The validity of the overall trend statistic is dependent on homogeneity between seasons, between stations, and a non-significant season-station interaction term. Procedures to evaluate these criteria and evaluate a global trend are computationally intensive and are not described in this report.

2.7 LOWESS

LOWESS stands for locally weighted scatterplot smoothing (Cleveland et al., 1979). It is not a monotonic trend analysis technique. It is a data smoothing algorithm that uses a moving window superimposed over a graph of data, with analyses being performed with each move, to produce a smoothed relationship of the two variables. Data near the center of the moving window influences the smoothed value more than those farther away. The smoothed relationship is then plotted as the LOWESS line. It provides a very good graphical depiction of the underlying structure of the data. LOWESS lines are included on each of the NMC GWMA time series plots in Appendix B. In addition, page B-42 of Appendix B depicts the LOWESS lines through the nitrate data from each sample location plotted at the same scale to allow comparisons between network wells.

An advantage of LOWESS is that no model, such as a linear or quadratic function, is assumed prior to computing a smoothed line. As such, LOWESS is an exploratory tool for discerning the form of relationship between y and x. Because no model form is assumed, the data describe the pattern of dependence of y on x. LOWESS is particularly useful to emphasize the shape of the relationship between two variables on a scatterplot of moderate to large sample size.

Because a LOWESS line reflects the underlying pattern of the data and is not fitting a straight line through the data as all monotonic trend techniques do, it allows an evaluation of changes within a time series data set. For example, a monotonic trend analysis result may indicate a statistically significant downward trend in a water quality variable over a 10-year time frame. However, the LOWESS line may suggest that the water quality variable decreased for 8 years and increased during the last 2 years. As another example, a monotonic trend analysis result may not identify a statistically significant trend in a water quality variable over a 10-year time frame. However, the LOWESS line may suggest that the water quality variable increased for 5 years then decreased for 5 years. These observations might be valuable and would not be apparent from the monotonic trend analyses.

2.8 Predicting Future Concentrations

The ultimate question in analyzing time series data and computing trends is often "how long will it take?" until a particular event occurs. Answering this question requires predicting future concentrations. Predicting future concentrations with some degree of confidence requires advanced modeling techniques. This type of modeling commonly requires a considerable amount of data (e.g., hundreds of data points collected over regular intervals from a single sampling point). Environmental studies seldom include this much data. Each sample location in this study includes approximately 30 to 50 data points. Furthermore, specialized and relatively sophisticated statistical expertise is also required. Accurate prediction of future groundwater concentrations is beyond the scope of this report. That being said, crude estimates of future concentrations were made in this report to provide some indication of when future concentrations may reach action levels. These estimates were made by extrapolating future concentrations from trend line slopes. It is important to realize the extreme limitations of these predictions. Perhaps the most important limitation is that contaminant concentrations do not decrease in a linear fashion so predictions made assuming a linear decrease will not be accurate. These predictions should be used as a crude first guess since the rigorous application of appropriate statistics was not accomplished.

3.0 DETERMINATION OF ANALYSIS SOFTWARE AND DATA SET

This section of the report provides information on the determination of which software was used, which data was included, and how data was conditioned prior to conducting the trend analysis.

3.1 Software Selection

The trend analysis software predominantly used in this analysis was WQHYDRO version 2031 developed by Eric R. Aroner. This software was selected primarily because it includes many types of trend analysis techniques as well as other useful statistical tests such as tests for theoretical distributions and presence of seasonality. A secondary reason for using WQHYDRO was DEQ's familiarity with the program and because it had been used in previous trend analyses. Future use of WQHYDRO will require the use of a more recent version of WQHYDRO, or the use of "dummy dates" because the software version used is not Y2K compliant in that it cannot analyze information with dates beyond 12/31/99. No data beyond 12/31/99 were used in this analysis.

Analyses which WQHYDRO cannot perform were conducted using the software Minitab version 12 by Minitab, Inc. and macros written by Dr. Dennis Helsel (with the United States Geological Survey (USGS)) and Dr. Edward Gilroy (retired from the USGS). Minitab is Y2K compliant and performs most, if not all, of the necessary statistical functions making it a potential software program for use in future trend analyses.

The geochemical plotting software used in this analysis was Plotchem version 7.9 by Tecsoft, Inc.

The use of product names is for information purposes only. DEQ does not advocate the use of any particular software.

3.2 Data Set

The length of the data set (i.e., the inclusive dates), which data to analyze, and the steps taken to condition the data are discussed in the following sections.

3.2.1 Length of Data Set

The Action Plan requires that nitrate trend analyses include data from July 1, 1991 until the date of the analysis. In accordance with the Action Plan, only data collected after July 1, 1991 was used in this study. This is not necessarily consistent with previous trend analyses (see Appendix C for more details). The data set for this study includes 8½ years of data from July 1991 through December 1999.

3.2.2 Data To Include In Analysis

Appendix A provides, in part, a comparison of trends calculated using two nitrate data sets: one data set consists only of cadmium reduction method data, while the other data set also includes electrode method data. As indicated in Appendix A, it was concluded to use only the nitrate data generated by the cadmium reduction method in this or future trend analyses.

3.2.3 Data Set Conditioning

The starting point for the data used in this study was a collection of WQHydro files from DEQ's July 1999 trend analysis. These files contained data from February 1991 through February 1998. Data both before and after this time frame were collected from DEQ's laboratory database as well as hard copies of original lab reports and other documents, then added to the electronic files.

Certain steps were taken to condition the data so that the trend analysis could be conducted. These steps included the following:

- Results from duplicate samples were averaged into one value.
- Samples reported as below a detection limit were recorded as one-half the detection limit. One-half the detection limit was chosen as a compromise between zero (which likely underestimates concentrations) and the detection limit (which likely overestimates concentrations).

- In cases where the detection limit changed over time due to more sensitive instrumentation, or when electrode method data (which has a higher detection limit) was included, then all data reported below the highest detection limit (1.0 ppm) were recorded as one-half the highest detection limit (0.5 ppm).
- The data were visually examined for obvious outliers and potential transcription errors. If a data point was suspected of being an error, efforts were made to trace the data back to the original laboratory report to confirm the result. Statistical outliers were not deleted from the data set.

4.0 METHODS

The methods selected for evaluation of water quality data were based on the Action Plan, recommendations from previous studies (summarized in Appendix C), and additional literature research. The methods used to evaluate water quality by aquifer as well as to evaluate trends of nitrate and DCPA & metabolites data are discussed below.

4.1 Evaluation of Water Quality by Aquifer

The wells used in this project derive water from the Sand & Gravel Aquifer and/or the Glenns Ferry Formation. An evaluation of water quality by aquifer was conducted to determine if water samples from different aquifers should be grouped separately prior to conducting a trend analysis. A brief discussion of these two aquifers is provided below. This information is from Gannett (1990). Following the aquifer descriptions is an evaluation of water quality using Stiff diagrams and Piper diagrams.

4.1.1 Sand & Gravel Aquifer

The uppermost aquifer is the Quaternary-aged[4] Sand & Gravel Aquifer. It is typically composed of 10 to 20 feet of fluvial (deposited by rivers) and eolian (deposited by wind) silt overlying 10 to 50 feet of fluvial sand and gravel. The silt is composed of crystal and lithic fragments with very little clay. The gravel is boulder- to cobble-sized clasts of mixed lithology in a coarse sand matrix. The Sand & Gravel Aquifer sediments generally correspond to present-day flood plains of the Snake and Malheur Rivers and Willow Creek plus deposits of older stream terraces and alluvial fan/terrace combinations. The Sand & Gravel Aquifer is bounded on all sides and on the bottom by the Glenns Ferry Formation.

4.1.2 Glenns Ferry Formation

Beneath the Sand & Gravel Aquifer (and extending tens of miles in every direction) is the Tertiary-aged[5] Glenns Ferry Formation. It is typically massive to bedded, very fine sandstone to medium siltstone with occasional interbedded coarser sand layers. The formation is lacustrine (deposited in a lake) in origin. The siltstone consists of lithic and crystal fragments and volcanic glass shards with trace to minor amounts of greenish brown flexible mica (chlorite?). The Formation also contains fish fossils, gastropod fossils, and diatoms. The Sand & Gravel Aquifer sediments may represent deposition by rivers onto the lake bed after the lake that formed the Glenns Ferry Formation drained.

4.1.3 Stiff Diagrams

In order to evaluate the validity of combining data from different GWMA wells into one or more data sets based on hydrogeology, an evaluation of water quality by aquifer was conducted. The evaluation consisted of the creation and examination of Stiff diagrams and Piper diagrams by aquifer. The aquifer from which each well derives water was obtained in one of three ways. The first method (the preferred method) was to use the aquifer designation as provided in Gannett (1990). The second method was to determine the aquifer from the lithologic description on the well log for a particular well. Finally, the third method was used at wells where no well log could be located and involved using the well depth in conjunction with well logs from nearby wells to infer the aquifer.

Stiff (1951) presented a system of plotting water quality analyses on a system of four parallel axes extending on each side of one vertical zero axis. Concentrations (in milliequivalents per liter) of four cations are plotted to the left of zero, while four anions are plotted to the right of zero. The resulting points are connected to give an irregular polygonal shape determined by the gross chemistry of the water. Comparing the shapes of Stiff diagrams is then used as an indication of water composition similarities and differences. The width of the pattern is an approximate indication of total ionic content.

[4] The Quaternary Period includes the span of time between 1.8 million years ago and the present.
[5] The Tertiary Period includes the span of time between 65 million years ago and 1.8 million years ago.

For this study, the cations plotted on the Stiff diagrams include sodium, calcium + potassium, magnesium + aluminum, and iron + manganese. The anions plotted include alkalinity (denoted as HCO_3) + nitrate, sulfate, chloride, and hardness (denoted as CO_3) + phosphate. Results of the water quality evaluation using Stiff diagrams are presented in Section 5.1.1.

4.1.4 Piper Diagrams
Piper (1944) presented a system of plotting multiple sample analyses on one diagram. The lower portion of the diagram consists of two trilinear diagrams representing the cation and anion content of the samples. These points are projected into the upper diamond-shaped portion of the diagram and combined into one point representing the combination of ions. Each sample is represented by one point on each portion of the diagram. Piper diagrams are useful for the plotting of many samples on one diagram to evaluate similarities and differences between groups of samples. Results of the water quality evaluation using Piper diagrams are presented in Section 5.1.2.

4.2 Trend Analyses at Individual Wells
In order to evaluate water quality trends at specific locations, the nitrate and DCPA & metabolites results from a particular well were analyzed for a monotonic trend using the Seasonal Kendall technique. See Appendix A for a comparison of results using various techniques. Results of the individual well trend analyses are discussed in Sections 5.3.1 (for nitrate) and 5.4.1 (for DCPA & metabolites).

4.3 Evaluation of Area-Wide Trends
The measures of Action Plan success regarding water quality trends relate to changes "for the entire management area." Therefore, in an attempt to evaluate area-wide water quality changes, three different methods of analysis were conducted. These included evaluating nitrate and DCPA & metabolites values using annual values, monthly values, and individual values. Each of these methods is described in more detail below.

4.3.1 Evaluation of Area-Wide Trends Using Annual Values
In order to evaluate area-wide nitrate changes on an annual basis, two data sets were constructed. These data sets consisted of the following:

- cadmium reduction method nitrate data from July 1991 through December 1999, and
- cadmium reduction method nitrate data from the years in which only this method was used (1994 through 1999).

The rationale to use only the cadmium reduction method nitrate data is discussed in Appendix A. Because only one method was used to quantify all DCPA & metabolites data, only one data set of those values was constructed.

Two different methods of central tendency (i.e., the median and average values[6]) were used to evaluate these data sets. For each of these data sets, the median value and average value of all wells sampled within a calendar year were calculated. The median and average values from each of the two data sets were then analyzed for monotonic trends using the Seasonal Kendall technique. Therefore, the evaluation of area-wide annual nitrate values was conducted 4 ways (2 data sets times 2 methods of central tendency equals 4). In each of these evaluations, the annual median or average nitrate value was assigned a date of June 15 of each year. A similar technique was used on DCPA & metabolites data to provide annual DCPA & metabolites concentrations. The difference is that there was only one data set of DCPA & metabolites data. Therefore, the evaluation of area-wide annual DCPA & metabolites values was conducted 2 ways (2 methods of central tendency).

[6] A median value is the middle number in a sequence of ranked values, or the average of the two middle numbers when a sequence has an even number of values. An average value (or arithmetic mean) is obtained by adding several values together and dividing the sum by the number of values.

Using annual values to evaluate area-wide trends is an imperfect tool for at least the following reasons: (1) each well was not sampled the same number of times each year (e.g., some wells are not available for sampling in the winter), (2) some wells were not sampled at all during some years, (3) some characteristics of the data set are lost when all data collected in a year are reduced to one value, and (4) this technique results in only a few data points with which to perform trend analyses.

In order to provide a crude estimate of when area-wide nitrate concentrations might reach the target level of 7 mg/l, the equation determining the trend line was rearranged and solved for time given a concentration of 7 mg/l. Results of the area-wide annual trend analysis are discussed in Sections 5.3.2.1 and 5.4.2.1.

4.3.2 Evaluation of Area-Wide Trends Using Monthly Values

In order to evaluate area-wide water quality changes on a monthly basis, two data sets were constructed. These data sets consisted of the following:

- cadmium reduction method nitrate data from July 1991 through December 1999, and
- cadmium reduction method nitrate data from the months in which only this method was used (October 1993 through December 1999).

As outlined in Section 4.3.1, two different methods of central tendency (i.e., the median and average values) were used to evaluate these data sets. For each of these data sets, the median value and average value of all wells sampled within a particular month were calculated. The median and average values from both data sets were then analyzed for monotonic trends using the Seasonal Kendall technique. Therefore, the evaluation of area-wide monthly nitrate values was conducted 4 ways (2 data sets times 2 methods of central tendency equals 4). In each of these evaluations, the monthly median or average nitrate value was assigned to the 15th day of that particular month. A similar technique was performed on DCPA & metabolites data to provide monthly concentrations. The difference is that only one method was used to produce all DCPA & metabolites data so there was only 1 data set. Therefore, the evaluation of area-wide annual DCPA & metabolites values was conducted 2 ways (2 methods of central tendency).

This is an imperfect tool for at least the following reasons: (1) each well was not sampled the same number of times each year, (2) some wells were not sampled at all during some years, and (3) some characteristics of the data set are lost when a sampling event is reduced to one value.

In order to provide a crude estimation of when area-wide nitrate concentrations might reach the target level of 7 mg/l, the equation determining the trend line was rearranged and solved for time given a concentration of 7 mg/l. Results of the area-wide monthly trend analysis are discussed in Sections 5.3.2.2 and 5.4.2.2.

4.3.3 Evaluation of Area-wide Trends Using Individual Values

Average Slope Method

One method used to evaluate area-wide trends using individual wells was to simply average the slopes of the trend lines at each sample location. In other words, a trend line was calculated for each of the sample locations. Each trend line has an associated slope. The average of these slopes was calculated and used to gauge the area-wide trend. This "average slope" method was performed on the data set using only cadmium reduction method data from July 1991 through December 1999.

An advantage of this method is that it is easy to calculate and easy to understand. A disadvantage of this method is that all data from each well are reduced to a single value before being averaged into an area-wide value. It should be noted that this technique was not discussed in the environmental literature reviewed during this study and, therefore, may not withstand scrutiny by the statistical community. It was performed due to its simplicity to implement and understand.

Regional Kendall Test

The variation of the Seasonal Kendall test called the Regional Kendall test (see Section 2.6) was also performed to evaluate the area-wide trend. The Regional Kendall test was performed on two data sets:

- cadmium reduction method data from all wells sampled July 1991 through December 1999, and
- cadmium reduction method data from all wells sampled in months in which only that method was used to analyze all samples (October 1993 through December 1999).

The Regional Kendall test for DCPA & metabolites data was performed on the one data set.

The Regional Kendall test was set up such that each "well / month sampled" combination was defined as a "season." For example, each sample from well MAL005 sampled in February of any year was designated as belonging to season "MAL005Feb." MAL005Feb contains 7 data points. Using the data set with cadmium reduction data from all wells sampled July 1991 through December 1999, 1480 data points were grouped into 215 "seasons" with enough data to compute slopes. The total number of "seasons" with at least one data point was 227. If all 38 wells had been sampled every other month from July 1991 through December 1999, there would be 1938 data points and 228 "seasons." The data were evaluated to estimate a trend for each "season," then the individual trends were combined into an area-wide trend.

The Regional Kendall test is believed to be the best tool to evaluate the area-wide trend. The advantage of the Regional Kendall test is that it uses the individual data values rather than summary values when evaluating an area-wide trend in one test. In other words, values from the 38 wells sampled in each sampling event are used rather than reducing each sampling event into a single number. Disadvantages of this test include (1) it is not commonly performed and thus is not well documented in the environmental literature, and (2) it is not an intuitive procedure and thus can be difficult to comprehend.

WQHYDRO version 2031 does not perform the Regional Kendall test. This analysis was performed using Minitab and a macro written by Dr. Edward Gilroy and Dr. Dennis Helsel.

4.4 Analysis Along Groundwater Flow Paths

In order to evaluate water quality trends along groundwater flow paths, four pairs of wells were identified which are likely to be along groundwater flow paths. Specific well pairs were determined by examining Plate 2 of Gannett (1990) which includes March 1989 water level contours of the shallow alluvial aquifer. Wells lining up approximately perpendicular to contours on Plate 2 of Gannett (1990) were assumed to be along a groundwater flow path. An effort was made to select well pairs from differing portions of the GWMA. Well pairs were selected from the eastern, central, western, and southern portions of the GWMA where water table contours have been mapped.

The water table contours from Gannett (1990) and the four well pairs are indicated in Figure 4-1 and described below. Well pair #1 includes the upgradient well MAL041 located near Cairo Junction and the downgradient well MAL016 located northeast of MAL041 in Ontario. Well pair #2 includes the upgradient well MAL121 located along Railroad Avenue south of Malheur Butte and the downgradient well MAL101 located north of MAL121 and just south of the Malheur River. Well pair #3 includes the upgradient well MAL116 located approximately three miles northwest of Vale along US Hwy 26 and the downgradient well MAL129 located southeast of MAL116 and just northeast of Vale. Well pair #4 includes the upgradient well MAL211 located just west of SR 201 approximately one mile north of Nyssa and the downgradient well MAL078 located just east of SR 201 approximately one mile north of Nyssa.

Nitrate and DCPA & metabolites time series graphs were prepared for the four well pairs. Travel times between upgradient and downgradient wells in each well pair were calculated based on area-wide porosity and hydraulic conductivity estimates from Gannett (1990) and individual hydraulic gradient estimates from Plate 2 of Gannett (1990). Results of the analyses (including discussions of the link between water quality at upgradient and downgradient wells), as well as the limitations of this technique, are presented in Sections 5.3.3 and 5.4.3.

5.0 RESULTS

Results of the evaluation of groundwater quality by aquifer as well as results of the trend analysis of nitrate and DCPA & metabolites data are discussed below.

5.1 Water Quality by Aquifer

As indicated in Section 4.1, Stiff diagrams and Piper diagrams were created and examined to evaluate the water quality of the different aquifers tapped by wells in the GWMA well network. The purpose of examining the water quality of the different aquifers is to evaluate whether the trend analysis data should be grouped together as one data set or divided into data sets based on aquifers. Discussions of the Stiff diagrams and Piper diagrams are presented in the following sections.

5.1.1 Stiff Diagrams

449 Stiff diagrams were created from water quality data collected between 1988 and 1999 from the 38 wells and 2 surface water locations within the GWMA network. The number of Stiff diagrams for each location ranged from 2 (MAL217 and MAL218) to 23 (MAL041). The data to construct these diagrams were collected from various months and various years.

The Stiff diagrams from each location were visually examined for similarities and differences. Most diagrams from a particular location were all similar to nearly identical. Notable exceptions include:

- MAL062 where the diagrams were similar from 1989 until 1995 when sodium began decreasing and sulfate began increasing,
- MAL079 where sodium decreases over time,
- MAL083 where sulfate increases through time (samples were collected in 1988 through 1991 and then in 1999),
- MAL116 where sodium decreases over time,
- MAL129 where sulfate increases over time,
- MAL147 where samples reflect the installation of a water softener sometime in 1992. The installation of the water softener caused an increase in sodium but a decrease in calcium, magnesium, potassium, manganese, and hardness. Alkalinity, iron, aluminum, sulfate, chloride, nitrate, and phosphate remained approximately the same. Samples collected from 1989 through February 1992 represent "natural" or non-softened water and samples collected after August 1993 represent softened water.
- MAL152 where sulfate, calcium, sodium, and alkalinity vary over time,
- OWYDRN001 (a surface water sample) where the four samples are represented by three fairly distinctive shapes, and
- OWYDRN002 (a surface water sample) where the four samples are represented by two fairly distinctive shapes.

Based on this examination, one diagram was selected as representative of the water quality from that location. With five exceptions, the diagram selected as representative was the September 1999 sample (the most recent sample with the required analytes). The exceptions include:

- MAL147 where the February 1992 sample was selected as representative of water prior to the installation of the water softener,
- MAL172 where the August 1996 sample was selected as representative because the September 1999 sample was drastically different from the other samples (the chloride content was ten times the previous values and alkalinity was 1/30th the previous values,
- MAL180 where the August 1996 sample was selected because the well was not sampled in September 1999, and
- The two surface water samples (OWYDRN001 and OWYDRN002) because they were so variable and are not actually groundwater samples.

Figure 5-1 is a diagram with well locations plotted in relation to each other. A well location map is provided in Figure 1-2. The Stiff diagrams selected as most representative are plotted on Figure 5-1 as close to the well locations as possible. The diagrams are coded with hatch patterns representing the aquifer(s) from which each well derives its water. Twenty-two wells tap the Sand & Gravel Aquifer, 11 wells tap the Glenns Ferry Formation, and 5 wells tap both the Sand & Gravel Aquifer and the Glenns Ferry Formation.

The Stiff diagrams at the three pairs of well nests[7] (MAL211 & MAL218, MAL012 & MAL216, and MAL147 & MAL152) do illustrate some differences in water quality between aquifers at particular locations (Figure 5-1). The shape of the two Stiff diagrams in each well nest is slightly different. However, the diagrams at each well nest are more similar to each other than to other wells in the same aquifer at other well nests. This suggests there is a stronger relationship between general water quality and geographic location than between general water quality and a particular aquifer.

This suggestion is supported by the examination of the shape of the 11 Stiff diagrams from wells tapping the Glenns Ferry Formation (Figure 5-1). These diagrams are not particularly similar in shape and appear to be more similar to nearby wells regardless of the aquifer tapped.

Conclusion
Based on the above discussion of the Stiff diagrams, it is concluded that there is no distinct grouping of groundwater samples based on aquifer. Rather, geographic location appears to have a stronger influence on general water quality. This may be due to the fact that the Sand & Gravel Aquifer (and potentially the Glenns Ferry Formation) receives a large portion of its recharge from deep percolation of irrigation water and leaky canals and ditches. Although not included in this report, the Stiff diagrams from the two surface water locations illustrate that irrigation water quality differs from location to location and season to season across the area. This localization of recharge may cause the general water quality to be localized rather than "regionalized" and/or dependent upon a particular aquifer.

5.1.2 Piper Diagrams

A Piper diagram was constructed using the water quality information from the samples selected as representative of each well. The complete Piper diagram is shown as Figure 5-2. A close up of the bottom half of the upper portion of the Piper diagram is shown as Figure 5-3. The sample points on Figure 5-3 have been shaded according to aquifer type, and an ellipse has been drawn around the samples from each aquifer. As illustrated by Figure 5-3, the samples from each aquifer do not plot in distinct groups. There is substantial overlap between the groups. In fact, 5 of the 11 Glenns Ferry Formation samples (45%) also plot within the Sand & Gravel Aquifer group while 21 of the 22 Sand & Gravel Aquifer samples (95%) also plot within the Glenns Ferry Formation group.

Conclusion
Based on the above discussion of the Piper diagram, it is concluded that there is no distinct grouping of groundwater samples based on aquifer. Therefore, the data were not separated based on different aquifers prior to trend analysis.

5.2 Seasonality

The Kruskal-Wallis test was used to evaluate whether data varied according to season. The test evaluates the possibility that the median of one group of data (e.g., a season) is statistically different than the median of any another season (i.e., indicating seasonality). Results of the Kruskal-Wallis test are presented in confidence levels (e.g., 90% confidence level). Test results were used to select the appropriate trend analysis technique.

[7] A well nest is a group of wells completed at different depths but located close enough to one another to be considered "one location."

If a data set exhibited at least a 90% confidence level that the median of one month differed from any other month, it was considered to exhibit seasonality. A 90% confidence level was selected after personal communication with Dr. Dennis Helsel (June 22, 2000). A relatively high confidence level was selected because seasonal tests lose power to detect trends when they are used on non-seasonal data.

Eight of thirty-eight wells and the two surface water samples exhibited seasonality in nitrate concentrations. Five of the eight wells (MAL064, MAL078, MAL101, MAL108, and MAL126) exhibited higher nitrate concentrations in the summer, two wells (MAL030, and MAL119) exhibited higher nitrate concentrations in winter, and one well (MAL180) exhibited higher nitrate concentrations in autumn. Both surface water samples (OWYDRN001 and OWYDRN002) exhibited higher nitrate concentrations in winter.

Four of thirty-eight wells and the two surface water samples exhibited seasonality in DCPA & metabolites concentrations. Two of the four wells (MAL101 and MAL108) exhibited higher DCPA & metabolites concentrations in the summer while the other two wells (MAL180 and MAL216) exhibited higher DCPA & metabolites values in the winter. Both surface water samples (OWYDRN001 and OWYDRN002) exhibited higher DCPA & metabolites concentrations in winter.

In other words, the two surface water samples and three of the four wells that exhibited seasonality in DCPA & metabolites also exhibited seasonality in nitrate, with maximum values at approximately the same time of year. One well exhibited seasonality in DCPA & metabolites but not in nitrate. Five wells exhibited seasonality in nitrate but not in DCPA & metabolites.

Figure 5-4 illustrates box plots for two wells (MAL030 and MAL126) exhibiting a 99% confidence level in nitrate seasonality. The nitrate fluctuations peak at different times of the year at these wells. The nitrate values are lowest in August at well MAL030 but highest in August at well MAL126 (Figure 5-4).

In an attempt to evaluate the timing and location of seasonality with respect to hydrogeology, a map was prepared which compared the season of maximum concentrations (both nitrate and DCPA & metabolites), the well depths, and the aquifer tapped by the well. Although not presented in this report, this map did not identify an apparent relationship between the season of maximum concentrations (both nitrate and DCPA & metabolites), the well depths, the aquifer tapped by the well, and the geographic location of the well.

Conclusion
Based on the above discussion of seasonality within the data, it was concluded that seasonality should be considered in choosing an appropriate trend analysis technique.

5.3 Nitrate Trends

The following discussion of nitrate trends is presented from several perspectives: trends at individual wells, area-wide trends, and trends along specific groundwater flow paths.

A basic component of the evaluation of trends at individual wells and trends along specific groundwater flow paths is the time versus concentration graph. Time versus concentration graphs for nitrate and DCPA & metabolites at each well are included in Appendix B. These graphs are oriented such that the time scales are coincident. This orientation allows the reader to gauge changes in nitrate concentrations and DCPA & metabolites concentrations at the same time.

Also included on the graphs in Appendix B are the monotonic trends discussed in the following sections (which provide an indication of the overall change in water quality from July 1, 1991 through December 31, 1999), as well as a LOWESS line (which provides an indication of the general pattern of the data).

5.3.1 Nitrate Trends at Individual Wells

The following discussion of individual nitrate trends consists of three aspects: the trend at each well, trends versus geographic location, and trends versus well depth.

Results of the nitrate trend analyses at individual wells include two basic pieces of information for each test performed: a slope value and a confidence level. The slope value indicates the direction and magnitude of the trend while the confidence level indicates the statistical certainty of the result. Trends are either increasing (i.e., have a positive slope), decreasing (i.e., have a negative slope), or flat (i.e., have a slope of zero). The confidence level associated with these test results range from less than 80% to 99%. For this study, test results with confidence levels less than 80% are considered "statistically insignificant". This does not mean that the concentrations observed at these wells are insignificant or unworthy of attention. Instead, this means that the statistical test could not identify a linear trend with a high degree of assurance.

All statistically insignificant trends are grouped together in this report. Statistically significant trends are divided into increasing, decreasing, or flat trends in this report. In addition, a distinction is made between wells exhibiting flat trends at low concentrations and wells exhibiting flat trends at elevated concentrations.

5.3.1.1 Nitrate Trends At Each Well

Table 5-1 includes some data set summary statistics for each well and summarizes the nitrate trend at each well. An examination of Table 5-1 reveals 15 increasing trends, 9 decreasing trends, 2 flat trends, and 14 statistically insignificant trends. It should be noted that the two trends identified as flat also exhibit low levels, indicating nitrate concentrations remained near the detection limit throughout the data set. It is not reasonable to expect decreasing nitrate trends at these locations. Of the statistically significant trends, several trends are approximately 0.1 ppm per year or less, and may not be physically meaningful.

It is important to note that 10 of the 14 wells exhibiting statistically insignificant trends have average nitrate concentrations above the target concentration of 7 mg/l; including the well with the highest average nitrate concentration (46 ppm at well MAL211). As previously indicated, the fact that a statistically significant linear trend cannot be drawn through the data does not mean the concentrations are insignificant or unworthy of attention. It is noteworthy that the 10 ppm drinking water standard for nitrate was exceeded at least once at 27 of the 38 wells; and that the average nitrate concentration exceeded the drinking water standard at 20 of the 38 wells.

The fact that statistically significant trends cannot be drawn through the data at some wells indicates the data are not "well behaved" (i.e., the data exhibit significant variability) and, in some cases, may suggest a shift in trend direction within the data set. For example, some of these wells exhibit concentrations that generally increase for a few years and then generally decrease for a few years. The test is unable to draw a statistically significant line through these data. However, a general increase in nitrate followed by a general decrease in nitrate may, in fact, indicate the desired effect of BMP implementation delayed by the complicating factors discussed in Section 5.4. Examination of the LOWESS line on the graphs in Appendix B illustrates this change in trend at some wells.

Conclusion

The monotonic trends at individual wells include predominantly increasing and statistically insignificant trends but also include decreasing and flat trends. Examination of LOWESS lines through the nitrate data illustrate more subtle changes in concentration over time.

5.3.1.2 Nitrate Trends versus Geographic Location

Figures 5-5 and 5-6 illustrate the nitrate trends and average nitrate concentrations at each well. Symbols are placed at well locations indicating the trend direction and magnitude on Figure 5-5. Colors and numbers are placed at well locations indicating the average nitrate concentration on Figures 5-6.

An examination of Figures 5-5 and 5-6 illustrates the following observations:

- The Ontario/Cairo Junction area has a mix of increasing, decreasing, and insignificant trends at wells with low, moderate and elevated nitrate levels,
- The Pioneer School area has a mix of increasing, flat, and insignificant trends at wells with moderate and elevated nitrate levels,
- The area north of Nyssa has predominantly decreasing trends but also has increasing and insignificant trends at wells with moderate and elevated nitrate levels,
- The Vale area has predominantly insignificant trends but has one decreasing trend at wells with predominantly low nitrate levels,
- The Owyhee River area wells exhibit insignificant or increasing trends at low to moderate nitrate levels; the surface water samples exhibit either an increasing or insignificant trend at low nitrate levels, and
- The Annex area has a mix of increasing and insignificant trends at wells with moderate to elevated nitrate levels.

Observing different trends in different geographic regions is consistent with expectations made during preparation and implementation of the Action Plan. For example, it was anticipated that groundwater quality would first improve in the upper reaches of the valleys as BMPs were implemented near the beginning of groundwater flow paths, and take longer for groundwater quality to improve at lower elevations near the end of groundwater flow paths. The undetectable or decreasing nitrate concentrations in the Vale area are generally consistent with this expectation. However, the undetectable or increasing nitrate concentrations in the Owyhee River area are not. Both of these areas are in the upper reaches of a valley and nitrate concentrations were expected to decrease in both areas. It is recommended that BMP implementation in the Owyhee River area be reevaluated and fine-tuned.

The most dramatic increase and decrease in nitrate concentrations occurred in relative close proximity to one another, illustrating that large differences in water quality trends occur over short distances. The largest decrease (3.3 ppm / year at MAL083) and the largest increase (2.0 ppm / year at MAL119) are located at wells approximately two miles apart in the Cairo Junction Area. The nitrate concentrations versus time at these wells, the associated monotonic trend line, and LOWESS line are illustrated in Figures 5-7 and 5-8. The trend lines and LOWESS lines use only cadmium reduction method data.

An examination of Figure 5-7 reveals that the trend line indicates an overall downward trend in nitrate concentration since July 1, 1991. The LOWESS line suggests nitrate concentrations increased from 1988 to 1994 then decreased until 1997 and remained relatively constant since then. The flattening of the LOWESS line around 1997 suggests samples collected in 2000 and subsequent years may lessen the slope of the trend line.

An examination of Figure 5-8 reveals that the trend line indicates an overall upward trend in nitrate concentration since July 1, 1991. The LOWESS line suggests nitrate concentrations were relatively constant from 1988 through 1993 when they began to increase. The rate of increase was greatest from 1993 through 1997 then it appears to begin to flatten out. The apparent flattening of the LOWESS line around 1997 suggests samples collected in 2000 and subsequent years may lessen the slope of the trend line. The increasing trends at wells such as MAL119 may be an artifact of the complicating factors discussed in Section 5.4. However, as a precaution, it is recommended that BMP implementation in the vicinity of MAL119, and near other wells identified as increasing trends, and near wells with statistically insignificant trends but elevated average nitrate concentrations, be reevaluated and fine tuned.

Conclusion

It is concluded that nitrate trends (1) are undetectable or decreasing in the Vale area with generally low nitrate concentrations, (2) are undetectable or increasing in the Owyhee River area with generally low nitrate concentrations, (3) are undetectable or increasing in the Pioneer School area and Annex area with generally moderate to elevated nitrate concentrations, and (5) vary in both directions in the region from Ontario to Nyssa with nitrate concentrations ranging from low to moderate to elevated.

Trends are often more complicated that a straight line. Water quality changes seen in the data are smoothed by the LOWESS line and distilled to a straight line by the trend analysis. The smoothing often highlights changes over time while a straight line over-simplifies changes.

5.3.1.3 Nitrate Trends versus Well Depth

Figure 5-9 is a plot of nitrate trends versus well depth. The symbols indicate which aquifer the wells tap. As indicated by Figure 5-9, the shallower wells exhibit the steepest trends (both increasing and decreasing) while the deeper wells exhibit smaller trends. Increasing, decreasing, and insignificant trends are exhibited by wells in each aquifer. The largest decreasing trend is in a Glenns Ferry Formation well while the largest increasing trend is in a Sand & Gravel Aquifer well. As mentioned previously, these two wells are located approximately two miles apart. With the exception of one well, the Glenns Ferry Formation wells exhibit small trends (Figure 5-9).

Conclusion

Shallow wells exhibit the greatest magnitude of trends while deeper wells exhibit smaller trends. This is likely due to the fact that application of nitrate fertilizer and irrigation water, as well as BMP implementation, occurs at land surface thus creating a greater effect in near-surface wells.

5.3.2 Area-Wide Nitrate Trends

In order to evaluate the three measures of Action Plan success pertaining to water quality trends, area-wide nitrate trends were evaluated using annual values, monthly values, and individual values. As indicated in Section 2.6, all wells should show trends in the same direction and general magnitude for an overall trend to be meaningful. Therefore, because nitrate trends at individual wells were increasing, decreasing, flat, or statistically insignificant, the evaluations of area-wide nitrate trends should not be viewed as statistically meaningful. They are, however, provided here to give some idea of the overall water quality trend and to crudely estimate the amount of time required for groundwater quality to reach action levels.

5.3.2.1 Annual Area-Wide Nitrate Trends

Area-wide annual nitrate trends were evaluated using two different data sets and two different measures of central tendency. See Section 4.3 for a description of these data sets. The resulting rates of nitrate change were used to crudely estimate when the area-wide nitrate concentration might reach 7 mg/l. It should be noted that this trend analysis method (i.e., using a few annual average or median values) is not believed to produce high quality results but was conducted in accordance with suggestions made in previous DEQ correspondence (see Appendix A for more information).

Results of the analysis are summarized in Table 5-2 and discussed below. As discussed below, one data set and one measure of central tendency were selected as the most appropriate combination to provide the best estimation of trend using annual nitrate values.

The best method to evaluate an area-wide nitrate concentration using annual data is believed to be using the Seasonal Kendall test on average of the cadmium reduction method data collected in 1994 through 1999. The rationale for using the Seasonal Kendall test is two-fold: (1) it accommodates the complicating aspects of water quality data sets (e.g., missing data, non-normal distributions, censored data), and (2) it provides a more comparable set of results for comparisons made between wells and over time. See Section 2 for more information on the requirements of various statistical methods, and Appendix A for more information on the differences between results produced by various statistical methods.

The rationale for using the average value rather than the median value is that the average value is influenced by all samples while the median value is not directly influenced by outliers. The average values are more indicative of the entire volume of nitrate-rich water. Helsel & Hirsch (1992) conclude an average concentration better estimates pollutant loading than a median concentration. Evaluating average values therefore better answers the question "What is the *overall* change in nitrate concentration?" while evaluating median values better answers the question "What is the *typical* change in nitrate concentration?"

The results indicate the Seasonal Kendall technique estimates a statistically significant decreasing trend ranging from 0.14 ppm/yr to 0.31 ppm/yr (Table 5-2). The estimated date when the average nitrate concentration throughout the GWMA reaches 7 mg/l ranges from May 2016 to March 2050.

Figure 5-10 illustrates the area-wide annual average nitrate trend. The trend line illustrated in Figure 5-10 is the Seasonal Kendall trend line and slopes downward at approximately 0.31 ppm per year. The trend line is significant at a confidence level of 90%. The trend line in Figure 5-10 appears steep because the y-axis only spans 1.8 ppm. It is interesting to note that a relatively small change in trend line slope equates to a relatively large change in predicted dates. For example, data following a trend line slope of 0.31 ppm per year will reach the target concentration 28 years faster than data following a trend line of 0.14 ppm per year (Table 5-2).

Conclusion
This technique's best estimation of the area-wide trend is one that is decreasing at 0.31 ppm/yr, with the area-wide nitrate concentration reaching 7 mg/l in July 2022 (Table 5-2). However, trend analyses conducted with only 6 or 9 data points representing annual average or median values are statistically weak and should be viewed skeptically.

Furthermore, it should be noted that the estimation of when the area-wide nitrate concentrations might reach 7 mg/l is unrealistic because it is based on a straight line drawn through the data that assumes a constant rate of decline. The degree to which these estimations are unrealistic is unknown. Complicating factors include:

- Not all wells exhibit declining nitrate trends. As previously noted, trends at all stations contributing to an overall trend must be in the same direction for that overall trend to be meaningful. It is unknown when the increasing trends identified at some wells will reverse.
- Continued, and perhaps expanded, implementation of BMPs would be necessary to positively affect area-wide nitrate concentrations.
- An examination of time series plots of data analyzed in this report (presented in Appendix B) reveals variability, sometimes including seasonality, in the nitrate concentrations illustrating the fact that actual concentrations do not fit a straight line.
- Nitrate trends may behave similarly to contaminant concentrations at clean-up sites. At such sites, concentrations often follow an asymptotic decline whereby concentrations initially decline steeply with time followed by a period of slow decline with time leveling off at some residual concentration. If nitrate trends in the Northern Malheur County GWMA behave similar to these sites, it is unknown what the residual concentration would be. If the residual nitrate concentration is near 7 mg/l, the estimated date discussed above is very likely not far enough in the future. If the residual nitrate concentration is substantially below 7 mg/l, the estimated date may be more reasonable.

5.3.2.2 Monthly Area-Wide Nitrate Trends

Area-wide monthly nitrate trends were evaluated using two different data sets and two different measures of central tendency. The resulting rates of nitrate change were used to crudely estimate when the area-wide nitrate concentration might reach 7 mg/l. Results of the analysis are summarized in Table 5-3 and discussed below. As discussed below, one data set and one measure of central tendency were selected as the most appropriate combination to provide the best estimation of trend using monthly nitrate values.

Results of the area-wide monthly nitrate trend analyses indicate a slight downward trend in nitrate concentrations (a few tenths of a ppm per year). Depending on the data set used (i.e., which time frame of cadmium reduction method data was included) and the method of central tendency (i.e., the median or the average) used in the trend analysis, the estimated rate of decline and date when the area-wide nitrate concentration might reach 7 mg/l also varies (Table 5-3).

Figure 5-11 illustrates the annual average nitrate trend. The seasonality identified in this data set is apparent in that average concentrations are generally highest in the summer and lowest in the spring (Figure 5-11). The trend line illustrated in Figure 5-11 is the Seasonal Kendall trend line and slopes downward at approximately 0.20 ppm per year. The trend line is significant at a confidence level of 99%.

Conclusion
This technique's best estimation of the area-wide trend is one that is decreasing at 0.2 ppm/yr, with the area-wide average nitrate concentration reaching 7 mg/l in January 2036 (Table 5-3). The factors complicating the prediction date discussed in Section 5.3.2.1 also apply to these prediction dates.

5.3.2.3 Area-Wide Nitrate Trends Using Individual Values
Results of the area-wide nitrate trends using individual values are discussed below using both the Average Slope Method and the Regional Kendall Test. In addition, a discussion of area-wide nitrate trends is also included.

<u>Average Slope Method</u>
As indicated in Section 4.3.3, a trend line was calculated for each of the sample locations (38 wells and 2 surface water sample locations. Each trend line has an associated slope. The average of the slopes from the 38 wells was calculated as well as the average of the slopes from the wells with statistically significant trends. The average of the trend line slopes is –0.01 ppm per year (Table 5-1). These results suggest a very slight decline in nitrate concentrations on an area-wide basis.

<u>Regional Kendall Test</u>
The two data sets of individual nitrate values described in Section 4.3.3 exhibit a non-normal distribution and seasonality of the well ID / month sampled "seasons." These data set characteristics are consistent with the use of the Regional Kendall test, which was also used to evaluate area-wide trends using individual values. As indicated in Section 4.3.3, the Regional Kendall Test is believed to provide the best estimate of the area-wide trend.

Results of the Regional Kendall test indicate a flat trend (i.e., zero slope) at a confidence level of 90%. Of the 215 "seasons" which were combined into an overall trend, there were 33 decreasing, 2 flat, 44 increasing, and 136 insignificant trends.

Figure 5-12 illustrates the data used in this evaluation and the test result. Figure 5-12 consists of many stacks of data points at two-month intervals. Each of these stacks of data points represents one sampling event and contains one data point for each well sampled that event. An examination of Figure 5-12 reveals most data points from all sampling events are less than 30 ppm with many less than 20 ppm. The median value of these data is 12 ppm and the average value is 15. A few values greater than 50 ppm are evident, with the maximum value of 99 ppm occurring in August 1998. It is worth noting that the median nitrate value in December 1999 was 11.3 ppm and the average nitrate value in December 1999 was 13.4 ppm.

<u>Discussion of Area-Wide Nitrate Trend Analyses</u>
Figure 5-13 is a summary of the area-wide nitrate trend analyses. It contains all of the information within Figure 5-12 (the area-wide trend evaluated by the Regional Kendall test) plus the trend lines from Figures 5-10 (the area-wide annual average values) and 5-11 (the area-wide monthly average values). The average slope method results are also indicated on Figure 5-13. It should be noted that the four estimates of an overall area-wide nitrate trend suggest either a flat or slightly declining trend (up to 0.3 ppm decline per year) with the best estimate (i.e., the Regional Kendall result) suggesting a flat trend. It bears repeating that these overall trends are based on a set of wells exhibiting variable trend directions so that the overall trends are not statistically valid.

However, it is encouraging to note that none of these estimates suggest area-wide nitrate concentrations are increasing. Furthermore, considering the factors inhibiting rapid improvement in groundwater quality (Section 5.4) these results are not surprising. To put the area-wide nitrate trend analyses into context, a conceptual model of how an area-wide nitrate trend might develop in response to extensive agriculture followed by BMP implementation is presented in Figure 5-14. It is important to note that the axes in Figure 5-14 are relative scales. No values are included or implied.

As illustrated in Figure 5-14, the conceptual model assumes nitrate concentrations were at some low steady-state background concentration prior to the introduction of extensive agriculture. During the early years of agriculture, over-fertilization and over-irrigation cause the accumulation of nitrate in the unsaturated zone beyond the reach of plants and a dramatic increase of nitrate concentrations in groundwater. As BMPs that improve fertilization and irrigation practices are implemented, the nitrate loading at land surface decreases but the nitrate in the unsaturated zone beyond the reach of plants persists. As time progresses under BMP implementation, the nitrate in the unsaturated zone continues to leach, thus maintaining the increase of groundwater nitrate concentrations, but at a slower rate. When a sufficient amount of nitrate has moved through the system and fertilization and irrigation closely approximates crop needs, nitrate concentrations in groundwater stabilize. Eventually, under continued improvement and expansion of BMPs, groundwater quality gradually improves as the majority of remaining nitrate moves out of the unsaturated zone and through the groundwater system. Ultimately, nitrate concentrations are expected to reach a new steady-state concentration likely higher than the original background concentration (Figure 5-14).

An explanation for the flat to slightly decreasing area-wide trends calculated in this study that is consistent with the conceptual model is if these data reflect the portion of the conceptual model curve that is flattening out and beginning to decline (Figure 5-14). The measures of success in the Action Plan requiring area-wide nitrate concentrations of 7 mg/l, or even a statistically significant downward trend, within five years of BMP implementation were overly optimistic. It is clear that a longer time frame will be required for these measures of success to be met[8].

5.3.3 Nitrate Along Groundwater Flow Paths

As indicated in Section 4.4, nitrate trends along groundwater flow paths were examined at four pairs of wells located along four specific groundwater flow paths. Time series plots of these four well pairs are presented in Figures 5-15 through 5-18. Travel time calculations between wells are presented in Table 5-4. The groundwater flow velocity at these well pairs is approximately 4 to 13 feet per day and the travel time between these well pairs ranges from 0.2 to 11 years (Table 5-4). In summary, no link in water quality between upgradient and downgradient wells was identified. Each well pair is discussed separately below. Due to the short distance between wells, well pair #4 is likely the best well pair to detect water quality changes from an upgradient to a downgradient well.

Well Pair #1 - Figure 5-15 illustrates that the upgradient well of well pair #1 (MAL041) has almost always exhibited a higher nitrate concentration than the downgradient well (MAL016). The nitrate concentration at the upgradient well ranged from 16 to 21.6 and averaged 17.9 ppm while the nitrate concentration at the downgradient well ranged from 8.55 to 19 and averaged 13.3 ppm (Table 5-1). The monotonic trend analyses (discussed in Section 5.3.1.1) indicate nitrate is increasing at MAL041 at 0.20 ppm/year while nitrate is decreasing at MAL016 at 0.75 ppm/year. An examination of the LOWESS lines in Figure 5-15 suggests that nitrate at MAL041 remained fairly constant until 1997 then began increasing while nitrate at MAL016 increased from 1986 through the early 1990s followed by a decrease from 1995 through 1999. The relatively long estimated travel time between these wells (8.2 years) makes the detection of a mass of water moving between these wells difficult to detect on Figure 5-15, which spans approximately 13 years. Based on the above discussion, no obvious link between water quality at the upgradient and downgradient wells in well pair #1 was identified.

[8] DEQ reconsidered the five year time frame for improving groundwater quality during preparation of the Action Plan for the second GWMA in Oregon: the Lower Umatilla Basin GWMA. The Lower Umatilla Basin GWMA was declared after the Northern Malheur County GWMA and the LUB Action Plan was finalized in 1997. In the Lower Umatilla Basin GWMA, groundwater quality data is to be collected for 12 years following Action Plan adoption before the first area-wide trend analysis is conducted.

Well Pair #2 – Figure 5-16 illustrates that the upgradient well of well pair #2 (MAL121) has almost always exhibited a higher nitrate concentration than the downgradient well (MAL101). The nitrate concentration at the upgradient well ranged from 12 to 15 and averaged 13 ppm while the nitrate concentration at the downgradient well ranged from 1.3 to 22 and averaged 8.6 ppm (Table 5-1). The monotonic trend analyses (discussed in Section 5.3.1.1) indicate no significant nitrate trend at MAL121 while nitrate is decreasing at MAL101 at 0.62 ppm/year. An examination of the LOWESS lines in Figure 5-16 suggests nitrate concentrations have remained relatively constant at MAL121 while concentrations at MAL101 increased through 1995 then started declining. The relatively short estimated travel time between these two wells (1.5 years) could allow the detection of a mass of water moving between these wells by examining Figure 5-16. However, no obvious link between water quality at the upgradient and downgradient well in well pair #2 was identified.

Well Pair #3 - Figure 5-17 illustrates that nitrate concentrations at the wells of well pair #3 have most often been quite similar. The nitrate concentration at the upgradient well (MAL116) ranged from 2.3 to 19 and averaged 5.2 ppm while the nitrate concentration at the downgradient well (MAL129) ranged from 2.6 to 8.1 and averaged 4.2 ppm (Table 5-1). The monotonic trend analyses (discussed in Section 5.3.1.1) indicate no significant nitrate trend at both wells. An examination of the LOWESS lines in Figure 5-17 suggest the wells have alternated having the higher concentration (i.e., the upgradient well was lower, then higher, then lower than the downgradient well). Figure 5-17 also suggests nitrate concentrations at these two wells sometimes fluctuate similarly (especially during 1996 through 1999). The relatively long estimated travel time between these wells (11 years) makes the detection of a mass of water moving between these wells almost impossible to detect on Figure 5-17, which spans approximately 11.5 years. In fact, if these wells are indeed along a flow path, no significant alteration of contaminant concentrations occurred, and the estimated travel times are correct, the elevated nitrate concentrations at MAL116 in 1993 and 1994 would not be detectable at MAL129 until 2004 or 2005. Based on the above discussion, no obvious link between water quality at the upgradient and downgradient wells in well pair #3 was identified.

Well Pair #4 - Figure 5-18 illustrates that the upgradient well of well pair #4 (MAL211) has almost always exhibited higher nitrate concentrations than the downgradient well (MAL078). The nitrate concentration at the upgradient well (MAL211) ranged from 16.2 to 76 and averaged 46 ppm while the nitrate concentration at the downgradient well (MAL078) ranged from <1 to 43.6 and averaged 8.9 ppm (Table 5-1). The monotonic trend analysis (discussed in Section 5.3.1.1) indicates no significant trend at MAL211 while nitrate is increasing at MAL078 at 0.53 ppm/year. These trends are also evident in the LOWESS lines. The short estimated travel time between these two wells (0.2 years) would allow for the detection of a mass of water moving between these wells by examining Figure 5-18. For example, the large fluctuations in nitrate concentrations at MAL211 in 1994 through 1996 should be detectable at MAL078. However, no obvious link between water quality at the upgradient and downgradient wells in well pair #4 was identified.

The large difference in average concentration between these wells (46 versus 8.9) indicates large differences in water quality occur over short distances (<1000 feet). This observation is consistent with a previous observation: large differences in water quality trends occur over short distances (Section 5.3.1.2).

As discussed above, no obvious link between water quality at upgradient and downgradient wells was identified. Furthermore, several complicating factors were identified which make the determination of a link in groundwater quality from these upgradient wells to these downgradient wells difficult.

Potential problems with the evaluation at all well pairs include:

1. The fact that water levels from March 1989 were used to prepare the map from which these well pairs were chosen; and that the current water table configuration may not be the same as it was then.
2. Land use in the vicinity of the well pairs may not be consistent throughout the time of investigation.
3. Large uncertainly about groundwater flow directions caused in part by the irrigation canals and ditches make it difficult to select downgradient wells.

4. Picking wells that are upgradient and downgradient of one isolated source is difficult, at best, when all available wells are monitoring the same area of nonpoint source pollution. A well truly upgradient of nonpoint source activities is not likely included in the bimonthly well network.
5. Large differences in water quality concentrations and trends occur over short distances indicating the complex distribution and behavior of nitrate in groundwater.

Potential complications with well pair #1 include:

1. MAL016 may not be exactly downgradient from MAL041. However, in an attempt to keep the only urban well in the network (MAL016) as a downgradient well, MAL041 was the best choice for an upgradient well.
2. Intense groundwater pumping with discharge to the Snake River occurs every irrigation season (typically April through October) in the area between these wells to prevent flooding of the low-lying area. This dewatering likely disrupts the natural groundwater flow paths in the vicinity of MAL041 and alters groundwater contaminant patterns.
3. During most of the 1900's a large feedlot and slaughterhouse were located approximately one mile southwest (upgradient) from MAL016. A substantial amount of manure was generated there and ultimately mixed with the native soil. It is possible that addition of this manure contributed to the nitrate concentration in the groundwater upgradient from MAL016.

A potential complication with well pair #2 includes the existence of the Dork canal between the two wells. This canal is a drainage canal and likely intercepts some of the groundwater (and its contaminants) traveling from the upgradient to the downgradient well.

A potential complication with well pair #3 is the fact that the wells are in close proximity to, and on opposite sides of, Willow Creek. Therefore, there is a high potential for surface water influences on groundwater quality.

Conclusion

No link in water quality between upgradient and downgradient wells was identified. Due to the short distance between wells, well pair #4 is likely the best well pair to detect water quality changes from an upgradient to a downgradient well. Several complicating factors likely contribute to the inability to establish a water quality link between upgradient and downgradient well pairs.

5.4 DCPA & Metabolites Trends

The following discussion of DCPA & metabolites trends is presented from several perspectives: trends at individual wells, area-wide trends, and trends along specific groundwater flow paths. Time versus DCPA & metabolites concentration graphs are included in Appendix B. Also included on the graphs are the monotonic trends discussed in the following sections as well as a LOWESS line. Evaluation of DCPA & metabolites trends was completed in accordance with recommendations made in previous DEQ correspondence (see Appendix C).

DCPA & metabolites concentrations in this data set range from <0.10 parts per billion (ppb) to 888 ppb. Average concentrations at individual wells range from <0.10 to 257 ppb. The current lifetime drinking water health advisory level for DCPA is 70 ppb (EPA, 2002)[9]. As indicated in Section 1.1, DCPA was not detected; only the metabolites have been detected. However, the 70 ppb Health Advisory level for DCPA includes DCPA and its metabolites (Abernathy, 2003).

Information available to EPA indicates that the "No Observed Effect Level" for the DCPA metabolite tetrachloroterephthalic acid (TPA) would be higher than that of DCPA (EPA, 1998). However, adequate information to estimate a health advisory level for TPA is not available (EPA, 1998). In other words, the health advisory level for TPA would likely be higher than that for DCPA if the data existed to calculate a health

[9] The lifetime health advisory for DCPA was 4,000 ppb at the time of Action Plan adoption. EPA's Office of Pesticide Programs recalculated the reference dose for DCPA which resulted in the recalculation of the DCPA health advisory by EPA's Office of Water. The revised lifetime health advisory for DCPA first appeared in the Summer 2000 version of the Health Advisory table.

advisory for TPA. Without a complete risk assessment database for each metabolite, EPA policy is to use a default assumption that each metabolite is no more or no less toxic than the parent. Therefore, the DCPA health advisory levels are the best available estimates for DCPA & metabolites health advisory levels. The 70 ppb health advisory level for DCPA & metabolites was exceeded at least once at 19 of the 38 network wells. The average DCPA & metabolites concentration exceeds the 70 ppb health advisory level at 9 of the 38 network wells.

5.4.1 DCPA & Metabolites At Individual Wells

The following individual DCPA & metabolites trends are discussed in several ways: the trend at each well, trends versus geographic location, and trends versus well depth.

5.4.1.1 DCPA & Metabolites Trends At Each Well

Table 5-5 summarizes results from the trend analyses and also includes some data set summary statistics. Results of the individual well DCPA & metabolites analyses indicate 5 increasing trends, 18 decreasing trends, 1 flat trend, and 16 statistically insignificant trends. Of the statistically significant trends, one decreasing trend (at OWY002) is less than 0.1 ppb per year and may not be physically meaningful.

5.4.1.2 DCPA & Metabolites Trends versus Geographic Location

Figures 5-19 and 5-20 illustrate the trends and average DCPA & metabolites concentrations at each well, respectively. Symbols are placed at well locations indicating the trend direction and magnitude on Figure 5-19. Colors and numbers are placed at well locations indicating the average DCPA & metabolites concentration on Figure 5-20. An examination of Figures 5-19 and 5-20 illustrates the following observations:

- The Ontario/Cairo Junction area has predominantly decreasing trends with a few increasing and insignificant trends at wells exhibiting the highest DCPA & metabolites concentrations in the study area,
- The Pioneer School area (north of Payette) is an even mix of decreasing and insignificant trends at wells exhibiting moderate to elevated levels of DCPA & metabolites,
- The area north of Nyssa has predominantly decreasing trends with one insignificant trend at wells exhibiting low to moderate DCPA & metabolites concentrations,
- The Vale area has either flat or insignificant trends at wells with low DCPA & metabolites concentrations,
- The Owyhee River area wells are a mix of increasing, decreasing, and insignificant trends at wells exhibiting low DCPA & metabolites concentrations, while the surface water samples exhibit insignificant trends at low DCPA & metabolites concentrations, and
- The Annex area (west of Weiser) has a mix of decreasing and increasing trends at wells ranging from low to elevated DCPA & metabolites concentrations.

As stated in Section 5.3.1, observing different trends in different geographic regions was expected. For example, groundwater quality was expected to first improve in the upper reaches of the valley as BMPs were implemented near the beginning of groundwater flow paths, and take longer to improve at lower elevations near the end of groundwater flow paths. This is not readily apparent by examining Figure 5-19. For example, all trends in the Vale area were flat or statistically insignificant. However, the low DCPA & metabolites concentrations in the Vale area make detection of statistically significant decreasing trends difficult or impossible.

Similarly, the samples collected in the Owyhee Junction area exhibit a mix of trend directions when decreasing trends were expected. However, the low DCPA & metabolites concentrations in the Owyhee Junction area also make detection of decreasing trends difficult.

The steepest decreasing DCPA & metabolites trend (30 ppb / year) was identified at MAL47 located near Cairo Junction. The steepest increasing DCPA & metabolites trend (13.6 ppb / year) was identified at MAL119 also located near Cairo Junction. The DCPA & metabolites concentrations versus time, the associated monotonic trends, and LOWESS lines for these wells are illustrated in Figures 5-21 and 5-22.

The Seasonal Kendall trend line and the LOWESS line for well MAL047 (Figure 5-21) are in relatively close agreement. The main difference is that the LOWESS line suggests a temporary increase in DCPA & metabolites concentrations in the mid 1990s before returning to a decreasing trend.

An examination of Figure 5-22 reveals that the Seasonal Kendall trend line indicates an increasing trend. However, the LOWESS line suggests concentrations at MAL119 increased in the early 1990s until about 1997, then decreased through 1999. The slope of the increasing trend is expected to lessen and eventually reverse as additional data are collected.

Conclusion

DCPA & metabolites trends are flat or undetectable at low values in the Vale area, are variable (but at low values) in the Owyhee River area, and are generally decreasing in the Annex area, Pioneer School area, Ontario area, and Nyssa area. Concentrations in these areas range from low to elevated with the highest concentrations located in the Cairo Junction Area.

5.4.1.3 DCPA & Metabolites Trends versus Well Depth

Figure 5-23 is a plot of DCPA & metabolites trends versus well depth. The symbols indicate which aquifer the wells tap. As was the case with nitrate, the shallower wells exhibited the steepest trends (both increasing and decreasing) while the deeper wells exhibited smaller trends. Both the largest decreasing trend and increasing trend are in wells producing from both aquifers.

5.4.2 Area-Wide DCPA & Metabolites Trends

In order to evaluate the area-wide DCPA & metabolites trend, trends were evaluated using annual values, monthly values, and individual values. As indicated in Section 2.6, all wells should show trends in the same direction and general magnitude for an overall trend to be meaningful. However, because 45% of the trends were decreasing and most trends (88%) are either decreasing, flat, or statistically insignificant, the overall DCPA & metabolites trend may still provide useful information.

5.4.2.1 Annual Area-Wide DCPA & Metabolites Trends

Area-wide annual DCPA & metabolites trends were evaluated using the two different measures of central tendency described in Section 4.3.1 (i.e., the median and average). The resulting rates of change were used to crudely estimate when the area-wide DCPA & metabolites might reach the 0.1 ppb detection limit. It should be noted that this trend analysis method (i.e., using a few annual average or median values) is not believed to produce high quality results but was conducted in accordance with suggestions made in previous DEQ correspondence. Results of the analysis are discussed below.

The trend estimated using average annual values decreased at a rate of approximately 5 ppb/yr while the trend estimated using median annual values decreased at a rate of approximately 1 ppb/yr. As described below, one data set and one method of central tendency were selected as the most appropriate combination to provide the best estimation of trend using annual DCPA & metabolites values. Following the rationale for using average values and the Seasonal Kendall method discussed in Section 5.3.2.1, the best estimate of the area-wide annual DCPA & metabolites trend is believed to be the Seasonal Kendall trend line drawn through average annual values as shown in Figure 5-24. As indicated in Figure 5-24, the trend decreases approximately 5 ppb/year. At this rate, DCPA & metabolites concentrations become undetectable throughout the GWMA in December 2004. All the limitations of the estimates of area-wide nitrate trends discussed in Section 5.3.2 also apply to area-wide DCPA & metabolites trends.

Conclusion

This technique's best estimation of the area-wide trend is one that is decreasing at 5 ppb/yr, with the area-wide DCPA & metabolites concentration becoming undetectable in December 2004. However, trend analyses conducted with only 9 data points representing annual average or median values are statistically weak and should be viewed skeptically.

5.4.2.2 Monthly Area-Wide DCPA & Metabolites Trends
Area-wide annual DCPA & metabolites trends were evaluated using the two different measures of central tendency described in Section 4.3.1 (i.e., the median and average). The resulting rates of change were used to crudely estimate when the area-wide DCPA & metabolites might reach the 0.1 ppb detection limit. Results of the analysis are discussed below.

The trend estimated using average monthly values decreased at a rate of approximately 4.1 ppb/yr while the trend estimated using median monthly values decreased at a rate of approximately 0.45 ppb/yr. As described below, one data set and one method of central tendency were selected as the most appropriate combination to provide the best estimation of trend using monthly DCPA & metabolites values. Following the previously discussed rationale for using an average value and the Seasonal Kendall method, the best estimate of area-wide monthly DCPA & metabolites trend is believed to be the Seasonal Kendall trend line drawn through average monthly values as shown in Figure 5-25. As indicated in Figure 5-25, the trend decreases at approximately 4.1 ppb/yr. At this rate, DCPA & metabolites concentrations become undetectable throughout the GWMA in July 2007. All the limitations of the estimates of area-wide nitrate trends discussed in Section 5.3.2 also apply to area-wide DCPA & metabolites trends.

Conclusion
This technique's best estimation of the area-wide trend is one that is decreasing at 4.1 ppb/yr, with the area-wide average DCPA & metabolites concentration becoming undetectable in July 2007. The factors complicating the prediction date discussed in Section 5.3.2.1 also apply to these prediction dates.

5.4.2.3 Area-Wide DCPA & Metabolites Trends Using Individual Values
Results of the area-wide DCPA & metabolites trends using individual values are discussed below using both the Average Slope Method and the Regional Kendall Test. In addition, a discussion of area-wide DCPA & metabolites trends is included.

<u>Average Slope Method</u>
As indicated in Section 4.3.3, a trend line was calculated for each of the sample locations (38 wells and 2 surface water sample locations. Each trend line has an associated slope. The average of the slopes from the 38 wells was calculated as well as the average of the slopes from the wells with statistically significant trends. This average slope method was performed on the data set summarized in Table 5-5. The average of the trend line slopes is –4.8 ppb per year. These results suggest a decline in DCPA & metabolites concentrations on an area-wide basis.

<u>Regional Kendall Test</u>
The data set of individual DCPA & metabolites values described in Section 4.3.3 exhibited a non-normal distribution and seasonality of the well ID / month sampled "seasons." These data set characteristics are consistent with the Regional Kendall test, which was used to evaluate area-wide trends using individual values.

Results of the Regional Kendall test using all DCPA & metabolites data indicate a decreasing trend (i.e., slope of –0.23 ppb/year) at a confidence level of 99%. Of the 215 "seasons" which were combined into an overall trend, there were 69 decreasing, 5 flat, 14 increasing, and 127 insignificant trends.

Figure 5-26 illustrates the data used in this evaluation and the test result. Figure 5-26 consists of many stacks of data points at two-month intervals. Each of these stacks of data points represents one sampling event and contains one data point for each well sampled that event. An examination of Figure 5-26 reveals most data points from all sampling events are less than 200 ppb with many less than 50 ppb. The median value of these data is 13.3 ppb and the average value is 56.3 ppb. A few values greater than 300 ppb are evident, with the maximum value of 888 ppb occurring in December 1991. The overall slope of all DCPA & metabolites data estimated by the Regional Kendall test is -0.23 ppb / year.

Discussion of Area-Wide DCPA & Metabolites Trend Analyses

Figure 5-27 is a summary of the area-wide DCPA & metabolites trend analyses. It contains all of the information within Figure 5-26 (the area-wide trend using individual values), the results of the average slope test, plus the trend lines from Figures 5-24 (the area-wide annual average values) and 5-25 (the area-wide monthly average values). Figure 5-27 illustrates that all four tests estimate a downward trend of area-wide DCPA & metabolites concentrations ranging from 0.23 to 5.0 ppb per year. The steeper slopes estimated by the average annual data and average monthly data are the result of the influence of the relatively few large values concentrated in the early part of the time series. It bears repeating that these overall trends are based on a set of wells exhibiting somewhat variable trend directions so the overall trends may not be statistically valid. However, the fact that all four area-wide tests and half of the individual wells indicate a downward trend is noteworthy.

Continued monitoring of DCPA & metabolites concentrations in the GWMA should provide information useful in assessing the nature of contaminant transport in the area. Because this analysis was conducted approximately four years after DCPA use essentially ended, the increasing DCPA & metabolites trends in wells located near the end of groundwater flow paths illustrates the need for a longer time frame to flush the aquifer. Furthermore, the travel time required for DCPA & metabolites to completely flush through the system will provide useful information in evaluating nitrate transport through the system.

5.4.3 DCPA & Metabolites Along Groundwater Flow Paths

As indicated in Section 4.4, DCPA & metabolites trends along groundwater flow paths were examined at four pairs of wells located along four specific groundwater flow paths. Times series plots of these four well pairs are presented in Figures 5-28 through 5-31. Travel time calculations between wells are presented in Table 5-5. The groundwater flow velocity at these well pairs is approximately 4 to 13 feet per day and the travel time between these well pairs ranges from 0.2 to 11 years (Table 5-4). In summary, no link in water quality between upgradient and downgradient wells was identified. Each well pair is discussed separately below.

Well Pair #1 - Figure 5-28 illustrates that the upgradient well of well pair #1 (MAL041) has always exhibited a higher DCPA & metabolites concentration than the downgradient well (MAL016). The DCPA & metabolites concentration at the upgradient well ranged from 88.5 to 764 and averaged 195.2 ppb while the DCPA & metabolites concentration at the downgradient well ranged from 4.6 to 83 and averaged 25.4 ppb (Table 5-5). The monotonic trend analyses (discussed in Section 5.4.1.1) indicate no significant DCPA & metabolites trend at MAL041 while DCPA & metabolites is decreasing at MAL016 at 1.83 ppb/year. The LOWESS lines in Figure 5-28 are consistent with the monotonic trends (i.e., no significant trend at MAL041 and a decreasing trend at MAL016). The relatively long estimated travel time between these wells (8.2 years) makes the detection of a mass of water moving between these wells essentially impossible to detect on Figure 5-28, which spans approximately 8.5 years. Based on the above discussion, no obvious link between water quality at the upgradient and downgradient wells in well pair #1 was identified.

Well Pair #2 – Figure 5-29 illustrates that the upgradient well of well pair #2 (MAL121) has always exhibited a higher DCPA & metabolites concentration than the downgradient well (MAL101). The DCPA & metabolites concentration at the upgradient well ranged from 8.55 to 213 and averaged 46 ppb while the DCPA & metabolites concentration at the downgradient well ranged from <0.1 to 2.5 and averaged 0.48 ppb (Table 5-5). The monotonic trend analyses (discussed in Section 5.4.1.1) indicate DCPA & metabolites is decreasing at MAL121 at 5.62 ppb/year while no significant DCPA & metabolites trend is detectable at MAL101. The LOWESS lines in Figure 5-29 are consistent with the monotonic trends (i.e., a decreasing trend at MAL121 and no significant trend at MAL101. The relatively short estimated travel time between these two wells (1.5 years) could allow the detection of a mass of water moving between these wells by examining Figure 5-29. However, no obvious link between water quality at the upgradient and downgradient well in well pair #2 was identified. It is interesting to note that these two wells are located on property where DCPA was not applied during the sampling period but DCPA has been applied to row crops on the property directly south (upgradient) of MAL121.

Well Pair #3 - Figure 5-30 illustrates that DCPA & metabolites concentrations at the wells of well pair #3 have most often been very low. The DCPA & metabolites concentration at the upgradient well (MAL116) ranged from <0.1 to 25.4 and averaged 2.07 ppb while the DCPA & metabolites concentration at the downgradient well (MAL129) ranged from <0.1 to 0.18 and averaged 0.06 ppb (Table 5-5). The monotonic trend analyses (discussed in Section 5.4.1.1) indicate no significant trend at MAL116 and a flat trend at MAL129. The LOWESS lines in Figure 5-30 are generally consistent with the monotonic trends (i.e., no significant trend or flat trend) except that the LOWESS line through MAL116 data gently increases from 1991 into 1995 then decreases to original levels and levels off. The relatively long estimated travel time between these wells (11 years) makes the detection of a mass of water moving between these wells impossible to detect on Figure 5-30, which spans approximately 7 years. In fact, if these wells are indeed along a flow path, no significant alteration of contaminant concentrations occurred, and the estimated travel times are correct, the elevated DCPA & metabolites concentrations at MAL116 in 1993 and 1994 would not be detectable at MAL129 until 2004 or 2005. It is interesting to note that well MAL116 also exhibited elevated nitrate concentrations in 1993 and 1994 (page B-18 in Appendix B). Based on the above discussion, no obvious link between water quality at the upgradient and downgradient wells in well pair #3 was identified.

Well Pair #4 - Figure 5-31 illustrates that DCPA & metabolites concentrations at the wells of well pair #4 have most often been very low. The DCPA & metabolites concentration at the upgradient well (MAL211) ranged from <0.1 to 10.2 and averaged 2.3 ppb while the DCPA & metabolites concentration at the downgradient well (MAL078) ranged from 0.25 to 17.7 and averaged 1.89 ppb (Table 5-5). The monotonic trend analyses (discussed in Section 5.4.1.1) indicate decreasing trends at both wells. The LOWESS lines in Figure 5-31 are consistent with the monotonic trends (i.e., decreasing significant trends at both wells). The short estimated travel time between these wells (0.2 years) would allow for the detection of a mass of water moving between these wells on Figure 5-31. For example, the elevated DCPA & metabolites concentrations in late 1994/early 1995 at MAL211 should be detectable at MAL078. However, no obvious link between water quality at the upgradient and downgradient wells in well pair #4 was identified.

Conclusion
As discussed above, no obvious link between water quality at upgradient and downgradient wells was identified. In addition, several complicating factors were identified which make the determination of a link in groundwater quality from these upgradient wells to these downgradient wells difficult. These complicating factors are discussed in Section 5.3.3.

5.5 Factors Inhibiting Rapid Improvement in Groundwater Quality

Several factors inhibit the rapid improvement of groundwater quality in the study area. These involve both hydrogeologic and cultural factors and include, but are not necessarily limited to, the following:

- *The source of aquifer recharge* – Gannett (1990) reports that the shallow groundwater system in the study area is recharged from a number of sources including precipitation, leakage from irrigation canals and ditches, deep percolation of water applied to fields, and infiltration from intermittent streams. There is also minor recharge from individual on-site sewage disposal systems (septic tanks) and municipal sewage lagoons. In addition, individual aquifers may receive recharge from adjacent geologic units. Gannett (1990) concludes that within the irrigated portion of study area, precipitation is relatively insignificant when compared to recharge from canal leakage and deep percolation of irrigation water. Therefore, the principal source of recharge to the shallow groundwater system is from the conveyance, distribution, and use of surface water for irrigation. Although the percentage of groundwater recharge coming from canal leakage versus deep percolation of irrigation water cannot be directly calculated due to the lack of specific data, the presence of agricultural chemicals in the shallow groundwater suggests that deep percolation of water applied to fields is occurring (Gannett, 1990). Therefore, the level of water in a well and the contaminants in the groundwater are directly influenced by water in the closest ditches and adjacent irrigation. In other words, because a significant percentage of aquifer recharge comes from irrigation water, much of the recharge is not pristine water but contains the agricultural chemicals that are the focus of this investigation.

- *Nitrogen in the unsaturated zone* – Due to past practices, considerable amounts of nitrate and ammonia exist below the root zone and above the water table. It has been estimated that approximately 50 million pounds of nitrogen was present in this zone which is unavailable for plant uptake but has not yet reached the groundwater system. Therefore, it is expected that some wells will exhibit upward nitrate trends, as this nitrogen is leached into the groundwater system, prior to exhibiting downward nitrate trends.

- *Nitrate in upgradient groundwater* – Contaminant concentrations at any well are influenced in part by the contaminant concentrations in upgradient groundwater. As this upgradient groundwater reaches a well, it provides a baseline of contamination that is then affected by activities nearer the well. Therefore, it is expected that some wells will exhibit upward nitrate trends prior to exhibiting downward nitrate trends because they are located downgradient of areas with greater contamination.

- *Groundwater flow velocity* – Gannett (1990) estimates the rate of groundwater movement ranges from 2 to 10 feet per day over much of the study area. In addition, the groundwater flow velocity at specific locations could be reduced by the interaction of canals, ditches, and other waterways. Therefore, groundwater can take many years (perhaps more than a decade) to travel through the aquifer and discharge into the Malheur or Snake River.

- *Continued use of nitrogen* – Nitrogen fertilizer is a primary nutrient element that limits crop production in Malheur County. Therefore, nitrogen fertilization could not end, or even be reduced below the levels needed by crops, without substantial negative economic impacts.

- *Existing irrigation systems* – Existing irrigation systems are predominantly flood/furrow systems, which inevitably result in deep percolation and leaching. Alternative irrigation systems have generally been cost prohibitive to install. Furthermore, there is no public will to make the social overhead capital investments necessary to rebuild irrigation systems. Other types of public systems could deliver water in ways that would make other types of irrigation more feasible.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the information presented in this report, several conclusions were drawn. The major conclusions drawn from this study are:

- The three measures of Action Plan success based on groundwater quality values have not yet been met. These measures of success were overly optimistic; it is clear that a longer time frame will be required for these measures of success to be met, and
- The area-wide nitrate trend appears to be no longer increasing. This conclusion is based on four estimates of the area-wide nitrate trend that suggest it is either flat or slightly declining (up to 0.3 parts per million (ppm) per year). This conclusion is not definitive because the nitrate trends at individual wells were mixed (i.e., they included 37.5% increasing, 22.5% decreasing, 5% flat, and 35% statistically insignificant[10] trends).

More detailed conclusions drawn from this study include the following, and are grouped by subject:

Data Analysis

- Because the electrode method data are generally higher than the cadmium reduction method data, and were collected during the early part of the time series, including the electrode method data in the trend analysis produces more statistically significant trends (three more decreasing and one more increasing), and also suggests a steeper area-wide decreasing trend.
- Due to the use of different analytical techniques, which may have been the cause of some data generated by the electrode method to be more variable and to not meet the project Quality Assurance Plan requirements for precision and accuracy, these nitrate data should not be used in this or future trend analyses.
- When summarizing data into monthly or annual values, it is best to use only those months and years in which one method (i.e., cadmium reduction) was used to analyze all nitrate samples.
- The Seasonal Kendall procedure should be used exclusively to quantify water quality trends in the NMC GWMA.
- Trends are often more complicated than a straight line, so using a data smoothing technique such as a LOWESS line can provide insight into non-linear changes within the data.

Water Quality By Aquifer

- No distinct groupings of groundwater samples based on specific aquifers were identified.
- Geographic location has a stronger influence on general water quality than the source aquifer does.
- It is not necessary to separate groundwater quality data based on specific aquifers prior to trend analysis.

Seasonality

- Seasonality was identified at the 2 surface water locations (in both nitrate and DCPA & metabolites data) and at some wells (8 of 38 wells in nitrate data; 4 of 38 wells in DCPA & metabolites data).
- Seasonal peaks in nitrate and DCPA & metabolites data occur at various times of year and at various locations.
- Seasonality should be considered when choosing an appropriate trend analysis technique.

[10] Because a well has a statistically insignificant trend does not mean that the concentrations observed at the well are insignificant or unworthy of attention. Instead, this means that a straight line could not be drawn through the data with a high degree of confidence.

Nitrate Concentrations and Trends

- The 10 ppm nitrate drinking water standard was exceeded at least once at 27 of the 38 wells while the average nitrate concentration exceeded the drinking water standard at 20 of the 38 wells.
- Nitrate trends at individual locations included 15 increasing trends (37.5%), 9 decreasing trends (22.5%), 2 flat trends (5%), and 14 statistically insignificant trends (35%).
- Nitrate trends are undetectable or decreasing in the Vale area with generally low concentrations.
- Nitrate trends are undetectable or increasing in the Owyhee River area with generally low concentrations
- Nitrate trends are undetectable or increasing in the Annex area and the Pioneer School area with generally moderate to elevated concentrations.
- Nitrate trends vary in both directions in the region from Ontario to Nyssa with concentrations ranging from low to moderate to elevated.
- Large differences in nitrate concentrations and trends occur over relatively short distances.
- Shallow wells exhibit steeper trends (both increasing and decreasing). Deeper wells exhibit smaller trends.
- Statistical literature summarized in Section 2.6 indicates that if nitrate trends at individual wells include increasing, decreasing, flat, and statistically insignificant trends, an area-wide trend is not statistically meaningful. Nevertheless, the four estimates made with the available data suggest the area-wide nitrate trend is either flat or slightly declining (up to 0.3 ppm per year).
- A conceptual model was developed that describes how an area-wide nitrate trend might develop in response to extensive agriculture followed by BMP implementation. An explanation for the flat to slightly decreasing area-wide trends that is consistent with the conceptual model is if this study's data reflect the portion of the conceptual model curve that is flattening out and beginning to decline.
- No link in nitrate concentrations between upgradient and downgradient well pairs was identified.

DCPA & Metabolites Concentrations and Trends

- The health advisory level for DCPA & metabolites was 4000 parts per billion (ppb) at the time of Action Plan adoption but has since been changed to 70 ppb. The current health advisory level was exceeded at least once at 19 of the 38 wells. The average DCPA & metabolites concentration exceeded the health advisory level at 9 of the 38 wells.
- DCPA & metabolites trends at individual locations included 5 increasing trends (12.5%), 18 decreasing trends (45%), 1 flat trend (2.5%), and 16 statistically insignificant trends (40%).
- DCPA & metabolites trends are flat or undetectable at low values in the Vale area.
- DCPA & metabolites trends are variable (but at low values) in the Owyhee River area.
- DCPA & metabolites trends are generally decreasing in the Annex area, Pioneer School area, and in the region from Ontario to Nyssa. Concentrations in these areas range from low to elevated with the highest concentrations located in the Cairo Junction area.
- Shallow wells exhibit steeper trends (both increasing and decreasing). Deeper wells exhibit smaller trends.
- The area-wide trend of the pesticide Dacthal and its breakdown products (termed DCPA & metabolites) appears to be decreasing. This conclusion is based on four estimates of the area-wide DCPA & metabolites trend that suggest it is decreasing at a rate of 0.23 to 5.0 ppb per year. This conclusion is not definitive because the DCPA & metabolites trends at individual locations are mixed (i.e., 45% decreasing, 40% statistically insignificant, 12.5% increasing, and 2.5% flat). However, because 88% of trends are either decreasing, flat, or statistically insignificant, an overall DCPA & metabolites trend may still provide useful information.
- Because this analysis was conducted approximately four years after DCPA use essentially ended, the increasing DCPA & metabolites trends in wells located near the end of groundwater flow paths illustrates the need for a longer time frame to flush the aquifer. Continued monitoring of DCPA & metabolites could provide useful information in assessing the nature of contaminant transport in the area thus allowing a more accurate evaluation of nitrate transport in the area.
- No link in DCPA & metabolites concentrations between upgradient and downgradient well pairs was identified.

Measures of Action Plan Success

The three measures of success based on groundwater quality values have not yet been met. The fourth measure of success (i.e., "other indicators of progress) is discussed in the companion document titled "Northern Malheur County Groundwater Management Area BMP Implementation Report". The overall success of the Action Plan is discussed in the document titled "Northern Malheur County Groundwater Management Area Action Plan Success".

Details of the three groundwater quality measures of Action Plan success are as follows:

1) The measure that nitrate levels for the entire management area reach 7 mg/l has not yet been met. The median and average nitrate concentrations from the December 1999 sampling event were 11.3 and 13.4 ppm, respectively.
2) The measure that a trend analysis indicates nitrate levels will reach 7 mg/l by July 1, 2000 was not met. The August 2000 sampling event results indicate median and average values exceeded 7 mg/l.
3) The measure that a statistically significant downward trend be demonstrated at the 80% confidence level has not yet been met. The four estimates of area-wide nitrate trends suggest either a flat or slightly declining trend (up to 0.3 ppm per year). Because nitrate trends at individual wells include increasing, decreasing, and flat or statistically insignificant trends, area-wide trend estimates are not statistically meaningful.

These measures of success were overly optimistic. It is clear that a longer time frame will be required for these measures of success to be met.

6.2 Recommendations

Based on the conclusions presented above, the following recommendations are made. These recommendations are grouped according to the responsible parties.

Groundwater Management Committee, Malheur County SWCD, NRCS, FSA, Malheur and Owyhee Watershed Councils, and Oregon State University

- Re-evaluate and fine tune BMP implementation in the Owyhee River area and near specific well locations with increasing nitrate trends and/or elevated nitrate concentrations.
- As appropriate and as resources allow, evaluate the possibility of point source contributions in the vicinity of wells with increasing nitrate trends.
- As available and appropriate, provide financial and technical support to assist in the continued research, documentation, and implementation of appropriate BMPs in the GWMA as well as projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

Groundwater Management Committee and DEQ with support from Federal, State, and County Agencies associated with this project

- Propose an amendment to the Action Plan that allows the use of the Seasonal Kendall method for the evaluation of water quality trends rather than requiring the use of the ordinary least squares method.

DEQ

- Continue the existing sampling plan (i.e., sample the 38 wells and 2 surface water bodies every other month) to maintain the water quality database.
- Perform another formal trend analysis of nitrate concentrations in 2005 using cadmium reduction nitrate data collected through December 2004.
- Eliminate the analysis of upgradient/downgradient well pairs in future trend analyses.
- As available and appropriate, provide financial and technical support to assist in the continued research and implementation of appropriate BMPs in the GWMA as well as projects such as deep soil sampling to evaluate changes in the amount and movement of nitrate within the unsaturated zone.

Although not directly related to the conclusions of this report, the following four recommendations are also made. It is believed that implementation of these recommendations could potentially improve and/or streamline the existing monitoring program. First, it is suggested that additional research be conducted to assess non-agricultural influences on the groundwater monitoring well network. If non-agricultural practices are affecting one or more of the network wells, a different set of BMPs would be necessary to address the nitrate loading at those locations. Second, it is suggested that a geostatistical analysis be performed to evaluate the appropriateness of the existing well network. The uneven distribution of wells throughout the GWMA may over-represent some areas while under-representing other areas. Third, it is suggested that a trend analysis be performed using the same data used in this report but using fewer samples per year from each well to evaluate the appropriateness of the sampling frequency. If similar results are obtained using fewer samples per year, the wells could be sampled less frequently, thus freeing up resources that could be redirected. Finally, it is suggested to evaluate the results of the geostatistical analysis and the reduced-frequency trend analysis to explore the possibility of reducing the sample frequency and/or modifying the existing well network to produce a cost-effective yet representative well network.

7.0 REFERENCES

Abernathy, Charles, 2003. Personal communication with Dr. Charles Abernathy of the USEPA Office of Water. May 21, 2002.

Cleveland, W.S., 1979, Robust Locally Weighted Regression and Smoothing Scatterplots: *J. Am. Stat. Assoc. 74*, 829-836.

EPA, 1997. Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Controls. EPA 841-B-96-004. 236 pgs.

EPA, 1998. Reregistration Eligibility Decision (RED) DCPA. EPA 738-R-98-005.

EPA, 2000. Guidance for Data Quality Assessment, Practical Methods for Data Analysis, EPA QA/G-9, QA00 Update, EPA/600/R-96/084. 162 pgs.

EPA, 2002. 2002 Edition of the Drinking Water Standards and Health Advisories. EPA 822-R-02-038.

Gannett, M. W., 1990, Hydrogeology of the Ontario Area, Malheur County, Oregon: Ground Water Report No. 34. Oregon Water Resources Department, 35 pg.

Gibbons, R. D., 1994, Statistical Methods For Groundwater Monitoring. John Wiley & Sons, Inc. 286 pgs.

Gilbert, R. O., 1987, Statistical Methods For Environmental Pollution Monitoring. John Wiley & Sons, Inc. 320 pgs.

Helsel, D.R. and R.M. Hirsch, 1992. Statistical Methods in Water Resources. Studies in Environmental Science 49, Elsevier Science B.V. Amsterdam. 529 pgs.

Hirsch, R. M., J. R. Slack, and R. A. Smith, 1982. Techniques of Trend Analysis for Monthly Water Quality Data, *Water Resources Research, Vol. 18, No. 1*, pg 107-121

Hirsch, R. M., and J. R. Slack, 1984. A Nonparametric Trend Test for Seasonal Data With Serial Dependence, *Water Resources Research, Vol. 20, No. 6,* pg 727-732.

Malheur County Groundwater Management Committee, 1991. Northern Malheur County Groundwater Management Action Plan, State of Oregon Department of Environmental Quality.

Piper, A. M. 1944, A Graphic Procedure in the Geochemical Interpretation of Water Analyses: *American Geophysical Union Transactions, v. 25*, pg.914-923.

Practical Stats Internet Site, 2000. http://www.practicalstats.com/Pages/tip.html October 2000 Tip of the Month**.** *Note that this web page changes monthly and is no longer available.*

Sawyer, C.N. and P.L. McCarty, 1978. Chemistry for Environmental Engineering, 3rd Edition.

Shock, C.C., 2000. Personal Communication with Phil Richerson of the Oregon Department of Environmental Quality on May 31, 2000

Shock, C.C., E.B.G. Feibert, L.B. Jensen. R.L. Jones, G.W. Capps and E. Gheen. 2001. Changes toward sustainability in the Malheur-Owyhee watershed. In Sustainability in Agricultural Systems in Transition Proceedings, ASA Special Publication no 64. American Society of Agronomy, Madison, WI.

Smith, D.G. and P.B. McCann (2000). Water Quality Trend Detection in the Presence of Changes in Analytical Laboratory Protocols. In Proceedings of the 2000 National Water Quality Monitoring Council. http://www.nwqmc.org/2000proceeding/papers/pap_smith(b).pdf

Stiff, H.A., Jr., 1951, The Interpretation of Chemical Water Analysis by Means of Patterns: Journal of Petroleum Technology, v.3, no. 10, pg 15-17.

Table 2-1
Comparison of Monotonic Trend Techniques Used In This Study
Northern Malheur County GWMA Trend Analysis Report

Trend Analysis Method	Parametric or Nonparametric	Account for Seasonality?	Advantages	Disadvantages
Simple Least Squares (Linear Regression)	Parametric	No	(1) The most powerful technique if data are normal, nonseasonal, & independent (2) Familiar technique to many people (3) Simple to compute a "best fit" line	(1) Environmental data rarely conforms to test assumptions (2) Sensitive to outliers (3) Difficult to handle non-detected values (4) Not robust against serial correlation (5) Does not account for seasonality
Mann-Kendall	Nonparametric	No	(1) Nondetects, outliers, and irregularly spaced data are permitted	(1) Does not account for seasonality (2) Not robust against serial correlation
Spearman Rho	Nonparametric	No	(1) Nondetects, outliers, and irregularly spaced data are permitted	(1) Not robust against missing observations (2) Does not account for seasonality (3) Not robust against serial correlation
Seasonal Least Squares Regression	Parametric	Yes, Deseasonalized values are obtained by subtracting monthly means averaged over years. The new values are then regressed against time.	(1) Accounts for seasonality (2) Produces a description of the seasonality pattern (i.e., seasonal means)	(1) Performs well only when data are normal (2) Not robust against serial correlation
Sine / Cosine Seasonal Least Square	Parametric	Yes, Deseasonalized values are obtained through fitting a sine curve through the data. The deviations from the curve are then regressed against time.	(1) Accounts for seasonality	(1) With few exceptions (e.g., temperature) there is little reason to believe the form of seasonality resembles a pure sine curve. (2) Performs well only when data are normal (3) Not robust against serial correlation
Seasonal Kendall without Correction for Correlation	Nonparametric	Yes, by comparing only data from the same "season".	(1) Accounts for seasonality (2) Robust against nondetects, outliers, and irregularly spaced data	(1) When applied to non-seasonal data, it has less power to detect trends than non-seasonal tests (2) Not robust against serial correlation
Seasonal Kendall with Correction for Correlation	Nonparametric	Yes, by comparing only data from the same "season".	(1) Accounts for seasonality (2) Robust against nondetects, outliers, and irregularly spaced data (3) Robust against serial correlation	(1) When applied to non-seasonal and/or non-correlated data, it has less power to detect trends than other tests.

Table 3-1
Comparison of Nitrate Split Samples
Northern Malheur County GWMA Trend Analysis Report

Well ID	Date	Electrode Method Result (ppm nitrate)	Cadmium Reduction Method Result (ppm nitrate + nitrite)	Relative Percent Difference
MAL005	6/15/1993	7.3	5.6	26%
MAL012	2/23/1993	35.5	35	1%
MAL012	6/17/1993	25.8	27	5%
MAL016	2/24/1993	12.6	12.5	1%
MAL016	6/16/1993	15	13	14%
MAL030	12/10/1991	41.5	28	39%
MAL030	2/23/1993	25.9	29	11%
MAL030	6/16/1993	28.8	27	6%
MAL041	2/24/1993	16.8	17	1%
MAL041	6/17/1993	29.3	18	48%
MAL044	12/15/1992	25.4	20	24%
MAL044	12/17/1992	25.4	20	24%
MAL044	6/17/1993	21	20	5%
MAL047	6/16/1992	26.5	29	9%
MAL047	10/7/1992	41	39	5%
MAL047	2/25/1993	33	33	0%
MAL047	6/15/1993	39	37	5%
MAL062	2/25/1993	36.3	32	13%
MAL062	4/13/1993	17.5	31	56%
MAL062	6/15/1993	28	27	4%
MAL064	4/13/1993	4.6	4	14%
MAL064	6/15/1993	6.3	4.6	31%
MAL078	2/24/1993	2.6	2.6	0%
MAL078	6/17/1993	9.9	8.5	15%
MAL079	2/24/1993	9.6	10	4%
MAL079	6/17/1993	12.8	10	25%
MAL083	2/25/1993	35.4	37	4%
MAL083	6/17/1993	36	37	3%
MAL101	10/17/1991	1.4	1.5	7%
MAL101	10/25/1991	1.4	1.5	7%
MAL101	6/16/1992	1.4	1.4	0%
MAL101	6/16/1992	1.4	1.4	0%
MAL101	2/25/1993	3.8	3.9	3%
MAL101	4/13/1993	8.5	8.6	1%
MAL101	6/16/1993	15	13	14%
MAL105	12/10/1991	32	22	37%
MAL105	10/7/1992	16	15	6%
MAL105	12/15/1992	28.2	23	20%
MAL105	2/23/1993	21	20	5%
MAL105	6/15/1993	18.7	17	10%
MAL106	4/13/1993	16.5	17	3%
MAL106	6/15/1993	30	27	11%
MAL106	6/15/1993	28.3	27	5%
MAL108	10/25/1991	2.6	1.8	36%
MAL108	2/23/1993	<1	0.65	0%
MAL108	6/17/1993	3.5	2.1	50%
MAL108	6/17/1993	2.5	1.8	33%
MAL116	12/10/1991	3.3	2.5	28%
MAL116	12/12/1991	3.3	2.5	28%
MAL116	4/13/1993	8	6.3	24%
MAL116	6/16/1993	7.3	5.6	26%
MAL119	6/17/1993	12.5	12	4%
MAL121	10/16/1991	19.4	15	26%
MAL121	4/14/1993	15.5	13	18%
MAL121	6/16/1993	15	14	7%
MAL125	4/13/1993	7.7	6.6	15%
MAL125	6/16/1993	8.1	6.5	22%
MAL126	10/25/1991	19.4	15	26%
MAL126	6/16/1993	9.6	8.2	16%
MAL126	6/16/1993	11.1	8	32%
MAL129	2/25/1993	3.8	3.9	3%
MAL129	6/16/1993	5.1	3.7	32%
MAL136	2/25/1993	11.3	13	14%
MAL136	4/14/1993	14.7	14	5%
MAL136	6/16/1993	14.8	13	13%
MAL147	12/15/1992	<1	<0.02	0%
MAL147	12/16/1992	<1	<0.02	0%
MAL147	2/25/1993	<1	0.08	0%
MAL147	4/13/1993	<1	0.02	0%
MAL147	6/15/1993	<1	0.05	0%
MAL152	6/15/1993	16.5	15	10%
MAL164	4/13/1993	9.6	8.5	12%
MAL164	6/16/1993	6.8	5.2	27%
MAL172	2/25/1993	12.2	13	6%
MAL172	4/13/1993	12.6	13	3%
MAL172	6/15/1993	12.7	12	6%
MAL175	10/25/1991	15.5	15	3%
MAL175	4/13/1993	12	12	0%
MAL175	6/15/1993	16.5	16	3%
MAL180	4/13/1993	10	5	67%
MAL180	6/16/1993	5.2	4	26%
MAL189	2/25/1993	8.2	8.5	4%
MAL189	6/16/1993	10.8	8.4	25%
MAL211	6/18/1992	52	48	8%
MAL211	10/7/1992	50	41	20%
MAL211	10/7/1992	50	41	20%
MAL211	2/24/1993	47	48	2%
MAL211	6/17/1993	50.2	49	2%
MAL216	2/23/1993	<1	0.04	0%
MAL216	4/14/1993	<1	0.04	0%
MAL217	4/13/1993	12.6	12	5%
MAL217	6/15/1993	14.8	14	6%
OWY002	2/24/1993	4.6	4.7	2%
OWY002	6/16/1993	5.1	4	24%
OWY009	10/18/1991	1	0.26	117%
OWY101	2/24/1993	8.4	8.5	1%
OWY101	6/16/1993	10.4	8.9	16%
OWYDRN001	2/24/1993	4.2	4.2	0%
OWYDRN001	6/17/1993	1.9	1.4	30%
OWYDRN002	6/16/1993	4.6	2.7	52%
OWYDRN002	6/16/1993	3.9	2.7	36%
Average		***16.6***	***14.2***	***15%***
# of Larger Electrode Method Values			***66***	***65%***
# of Larger Cadmium Reduction Method Values			***21***	***21%***
# of Values Equal			***14***	***14%***

Note:

Relative Percent Difference is a measure of laboratory precision as is calculated as follows:

*[(Difference between 2 results) / (Average of 2 results)] * 100*

Table 5-1
Summary of Individual Well Nitrate Trends
Northern Malheur County GWMA Trend Analysis

Sample Location	Data Set Statistics						Trend	
	Minimum	Maximum	Mean	Median	n	% BDL	Slope	Confidence Level
MAL005	4.25	7.7	6.17	6.7	41	0%	0.38	99%
MAL012	9.39	36	25.37	25.0	45	0%	-0.89	95%
MAL016	8.55	19	13.31	13	41	0%	-0.75	99%
MAL030	26	31	28.33	28	44	0%	0.22	95%
MAL035	19	35.7	29.59	30	44	0%	1.00	99%
MAL041	16	21.6	17.93	18	44	0%	0.20	95%
MAL044	15	22	18.55	18.6	44	0%	0.09	NS80
MAL047	21.8	48	34.71	35	46	0%	-0.99	NS80
MAL062	22.1	54	38.96	40	43	0%	1.33	80%
MAL064	0.07	22	7.37	7.8	44	0%	-0.30	NS80
MAL078	0.58	43.6	8.87	6.5	43	0%	0.53	80%
MAL079	3.51	18	9.28	9.5	40	0%	-0.54	80%
MAL083	8.9	47	24.42	21.2	38	0%	-3.30	99%
MAL101	1.3	22	8.57	7.3	43	0%	-0.62	80%
MAL105	15	33	26.13	28	47	0%	1.51	99%
MAL106	0.05	31	25.21	28	26	0%	0.63	90%
MAL108	0.1	4	1.05	0.52	46	0%	-0.04	95%
MAL116	2.3	19	5.23	3.9	30	0%	-0.25	NS80
MAL119	9.3	26	19.70	21	27	0%	1.99	99%
MAL121	12	15	13.03	13	45	0%	0.00	NS80
MAL125	5.1	24	10.90	8.8	32	0%	-0.60	NS80
MAL126	4.9	99	27.58	19.9	40	0%	0.55	NS80
MAL129	2.6	8.1	4.22	3.9	41	0%	-0.05	NS80
MAL136	7.78	14	9.88	9.8	44	0%	-0.76	99%
MAL147	0.01	0.36	0.03	0.01	44	64%	0.00	99%
MAL152	4.5	16	11.08	11	26	0%	0.49	NS80
MAL164	1.9	8.45	4.10	3.6	32	0%	-0.59	99%
MAL172	2	14	9.17	9.5	41	0%	-0.21	NS80
MAL175	10	22	14.86	14	44	0%	0.49	95%
MAL180	2.3	5.6	3.98	4	40	0%	0.08	NS80
MAL189	7.4	10	8.70	8.6	38	0%	0.10	99%
MAL211	16.2	76	46.04	48.5	32	0%	-0.50	NS80
MAL216	0.1	0.36	0.12	0.1	41	90%	0.00	95%
MAL217	12	20	15.44	15	40	0%	0.97	99%
MAL218	1.8	46.5	26.47	27	29	0%	-2.52	95%
OWY002	3.4	6	4.66	4.7	42	0%	0.10	99%
OWY009	0.01	7.1	2.89	2.9	26	4%	0.40	90%
OWY101	2.54	10	8.83	8.9	44	0%	0.04	NS80
OWYDRN001	0.98	6.85	3.91	4.2	39	0%	0.20	99%
OWYDRN002	1.4	6.9	4.11	4.9	39	0%	-0.03	NS80

# of Increasing Trends ==>	15
# of Decreasing Trends ==>	9
# of Flat Trends ==>	2
# of Insignificant Trends ==>	14
Average slope of significant trends at the 38 wells ==>	-0.01
Average slope of all trends at the 38 wells ==>	-0.05

Notes:

n = number of samples; BDL = below detection limit; NS80 = not significant at an 80% confidence level

E:\Malheur\3rd Draft\[all trends.xls]Nitrate Trends

Table 5-2
Annual Area-Wide Nitrate Trend Analyses Summary
Northern Malheur County GWMA Trend Analysis Report

Data Set Used in Trend Analysis	Method of Central Tendency Used in Trend Analysis	Trend Analysis Technique Used	Number of Data Points in Data Set	Rate of Nitrate Decrease (ppm / year)	Estimated Date of 7 mg/l Average Nitrate Concentration Throughout GWMA
Cadmium Reduction Method data only (1991 – 1999)	Median	Seasonal Kendall	9	0.25	May 2016
Cadmium Reduction Method data only (years when that was the only method used (1994 – 1999))	Median	Seasonal Kendall	6	A statistically insignificant downward trend was indicated	July 2026
Cadmium Reduction Method data only (1991 – 1999)	Average	Seasonal Kendall	9	0.14	March 2050
Cadmium Reduction Method data only (years when that was the only method used (1994 – 1999))	***Average***	***Seasonal Kendall***	***6***	***0.31***	***July 2022***

The bold result is believed to represent the best estimation. See Section 5.3.2.1 for a discussion.

Table 5-3
Monthly Area-Wide Nitrate Trend Analyses Summary
Northern Malheur County GWMA Trend Analysis Report

Data Set Used in Trend Analysis	Method of Central Tendency Used	Trend Analysis Technique Used	Number of Data Points in Data Set	Rate of Nitrate Decrease (ppm / year)	Estimated Date of 7 mg/l Average Nitrate Concentration Throughout GWMA
Cadmium Reduction Method data only (7/91 to 12/99)	Median	Seasonal Kendall	51	0.25	September 2015
Cadmium Reduction Method data only (Months when that was the only method used (10/93 to 12/99))	Median	Seasonal Kendall	38	0.28	January 2014
Cadmium Reduction Method data only (7/91 to 12/99)	Average	Seasonal Kendall	51	0.14	June 2053
Cadmium Reduction Method data only (months when that was the only method used (10/93 to 12/99))	***Average***	***Seasonal Kendall***	***38***	***0.20***	***January 2036***

The bold result is believed to represent this techniques best estimation. See Section 5.3.2.2 for a discussion.

Table 5-4
Travel Time Estimates Between Upgradient and Downgradient Wells
Northern Malheur County GWMA Trend Analysis

Well Pair	Distance between wells (ft)	Distance between wells (miles)	Head Difference between wells (ft)	i (ft/ft)	n	K (ft/day)	Ground water flow velocity (ft/day)	Travel time between wells (days)	Travel time between wells (years)
MAL041 & MAL016	18744	3.6	47	0.0025	20%	500	6.3	2990	8.2
MAL121 & MAL101	4576	0.9	15	0.0033	20%	500	8.2	558	1.5
MAL116 & MAL129	14168	2.7	20	0.0014	20%	500	3.5	4015	11.0
MAL211 & MAL078	972	0.2	5	0.0051	20%	500	12.9	76	0.2

Well pairs are wells within the Alluvual Aquifer located approximately perpendicular to water level contours
Distance estimated from Plate 2 in Gannett (1990) 1:62,500 scale
Head difference taken from Plate 2 in Gannett (1990) which are March 1989 water levels
i = horizontal hydraulic gradient = (head difference / distance)
n = effective porosity = the estimate used in Gannett (1990)
K = horizontal hydraulic conductivity = the estimate used in Gannett (1990)
GW Velocity = (K*i)/n
Travel time between wells = (distance / velocity)

Table 5-5
Summary of Individual Well DCPA & Metabolites Trends
Northern Malheur County GWMA Trend Analysis

Sample Location	Data Set Statistics						Trend	
	Minimum	Maximum	Mean	Median	n	% BDL	Slope	Confidence Level
MAL005	0.05	19.8	5.18	4.85	47	21%	1.77	99%
MAL012	74.6	759	215.4	184.0	49	0%	-14.55	80%
MAL016	4.6	83	25.4	24.2	46	0%	-1.83	80%
MAL030	89.6	795	202.4	173.5	48	0%	-13.03	90%
MAL035	61.1	541	215.0	191.5	49	0%	-15.53	95%
MAL041	88.5	764	195.2	174	48	0%	0.25	NS80
MAL044	9.4	120	34	29.5	48	0%	0.00	NS80
MAL047	37.9	888	257.2	211	49	0%	-29.93	99%
MAL062	2.3	198	67	66.1	48	0%	8.28	99%
MAL064	0.55	73	16.7	10.2	45	0%	-0.23	NS80
MAL078	0.25	17.7	1.89	0.94	43	0%	-0.22	99%
MAL079	1.23	88.4	10.02	4.27	42	0%	-1.13	99%
MAL083	3.6	240	87.4	70.6	39	0%	-15.79	99%
MAL101	0.05	2.5	0.48	0.27	45	36%	0.00	NS80
MAL105	14.2	339.5	96.3	83.6	48	0%	-0.03	NS80
MAL106	6.10	564	225	229	28	0%	-23.54	95%
MAL108	0.05	49	4.6	1.9	49	2%	-0.51	99%
MAL116	0.05	25.4	2.07	0.05	34	56%	0.00	NS80
MAL119	3.7	200	101.3	102	25	0%	13.62	90%
MAL121	8.55	213	46	36.4	49	0%	-5.62	99%
MAL125	0.05	194	23.2	7.1	35	6%	0.43	NS80
MAL126	0.05	0.3	0.07	0.05	38	90%	0.00	NS80
MAL129	0.05	0.18	0.06	0.05	43	95%	0.00	95%
MAL136	6.1	186	40.4	28.4	49	0%	-0.56	99%
MAL147	2.7	49.7	13.6	11.6	47	0%	-0.43	NS80
MAL152	3.2	261	59.6	43.2	30	0%	-8.69	95%
MAL164	0.05	1.6	0.14	0.05	36	92%	0.00	NS80
MAL172	0.05	13.1	2.6	1.3	46	2%	-0.13	NS80
MAL175	0.05	110	34.7	31	47	2%	-2.41	95%
MAL180	0.05	7.8	1.2	0.53	43	37%	0.00	NS80
MAL189	5.1	59.6	22.1	19.7	39	0%	-0.60	NS80
MAL211	0.05	10.2	2.3	1.3	34	9%	-0.46	99%
MAL216	1.0	11.1	4.25	2.7	43	0%	0.13	80%
MAL217	7.35	67.8	23.3	19.8	39	0%	-2.43	95%
MAL218	0.2	11.4	3.6	2.7	26	0%	-1.51	99%
OWY002	0.05	1.89	0.72	0.7	49	4%	0.08	99%
OWY009	0.05	0.79	0.16	0.05	27	56%	0.00	NS80
OWY101	1.6	49	9.4	5.5	49	0%	-1.00	99%
OWYDRN001	0.5	23.5	5.9	4.3	46	0%	0.21	NS80
OWYDRN002	0.6	20.2	3.6	2.7	46	0%	-0.13	NS80

# of Increasing Trends ==>	5
# of Decreasing Trends ==>	18
# of Flat Trends ==>	1
# of Insignificant Trends ==>	16

Average slope of significant trends at the 38 wells ==>	-4.79
Average slope of all trends at the 38 wells ==>	-3.04

Notes:

(1) n = number of samples; BDL = below detection limit; NS80 = not significant at an 80% confidence level

(2) Trends at MAL101, MAL116, MAL126, MAL129, MAL164, MAL180, and OWY009 are suspect due to high percentage of nondetects and low concentration of reported values.

Figure 1-1
Location of Northern Malheur County Groundwater Management Area
Northern Malheur County GWMA Trend Analysis Report

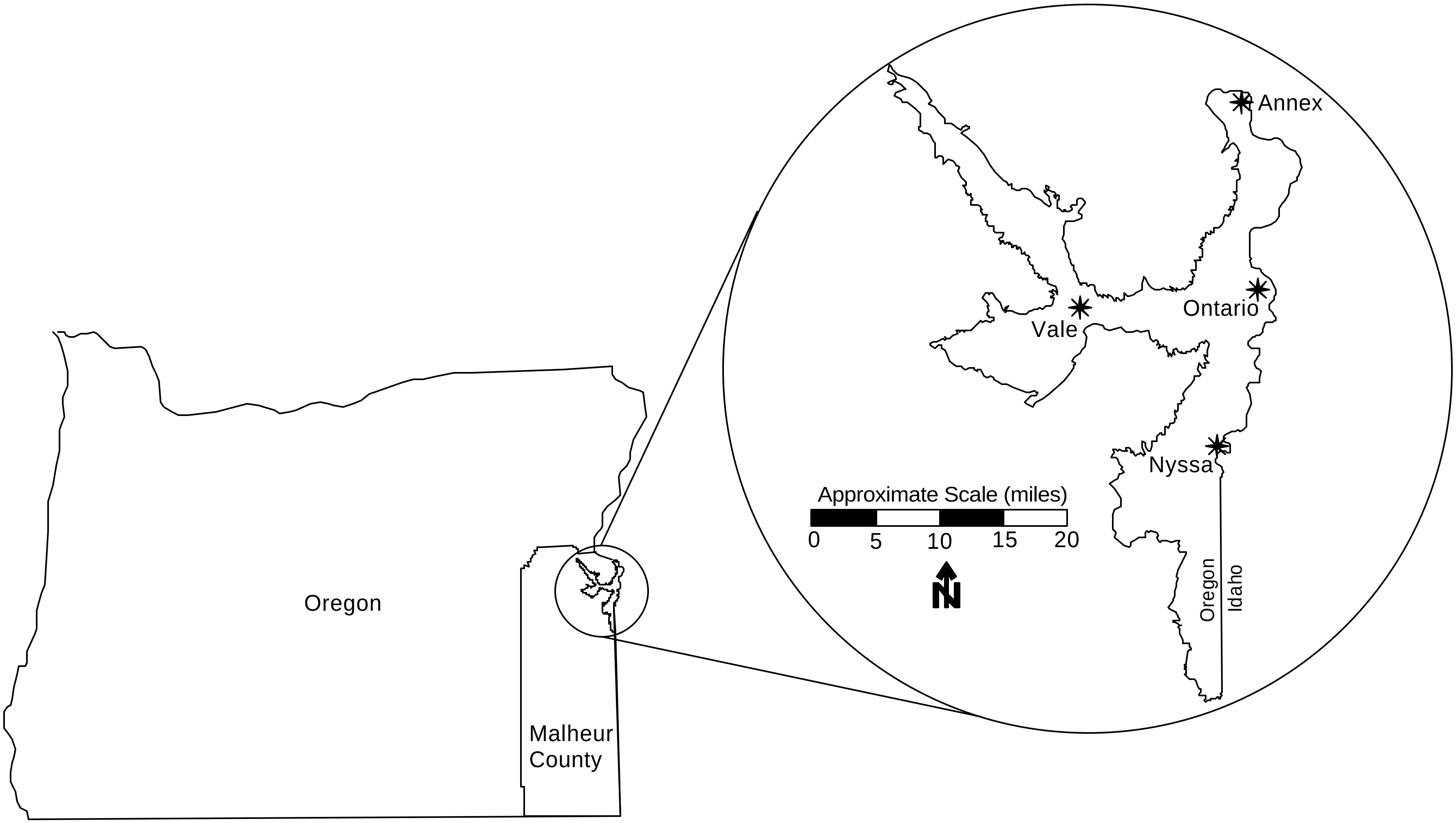


Figure 1-2
Well Location Map
Northern Malheur County GWMA Trend Analysis Report

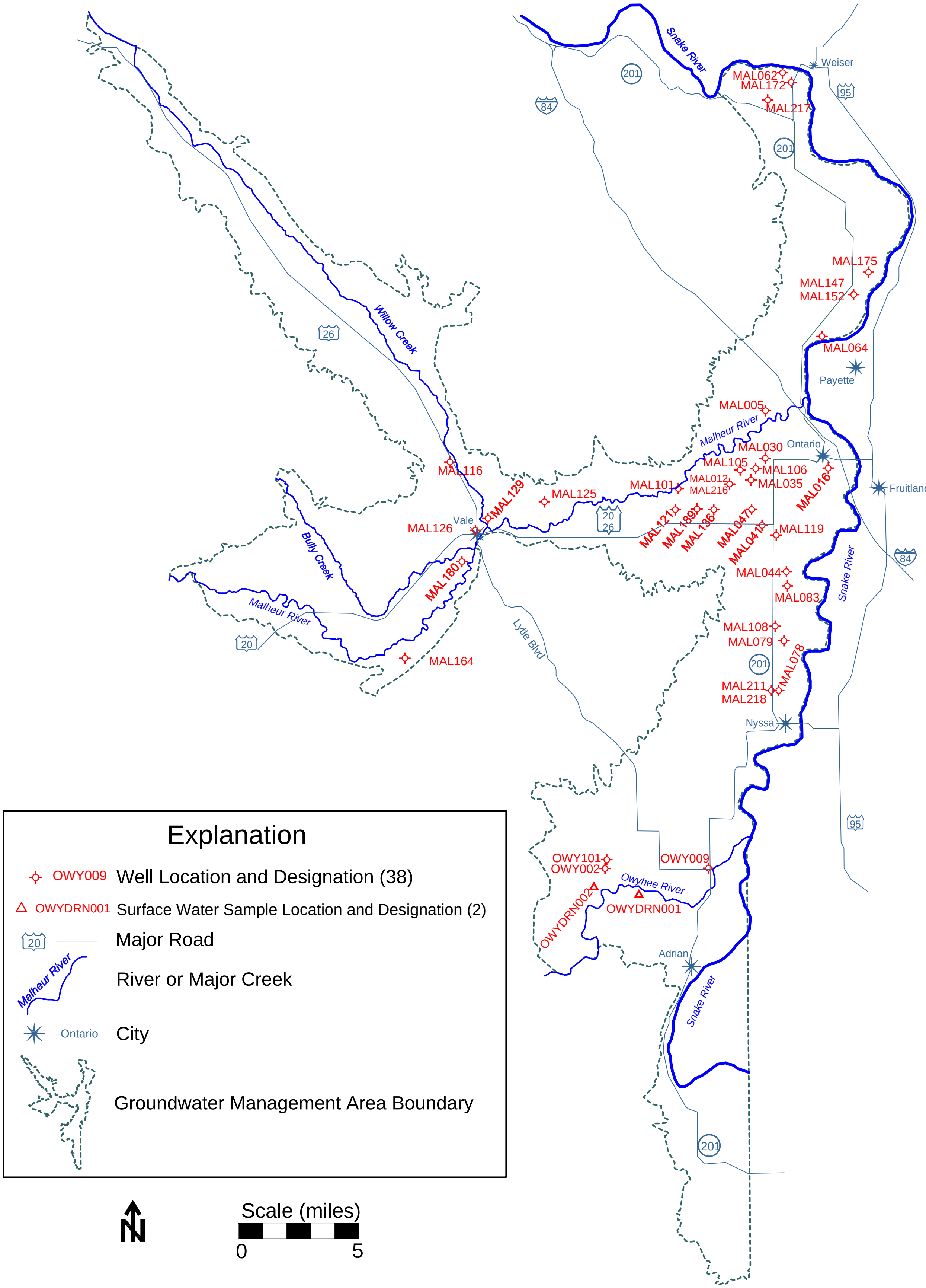
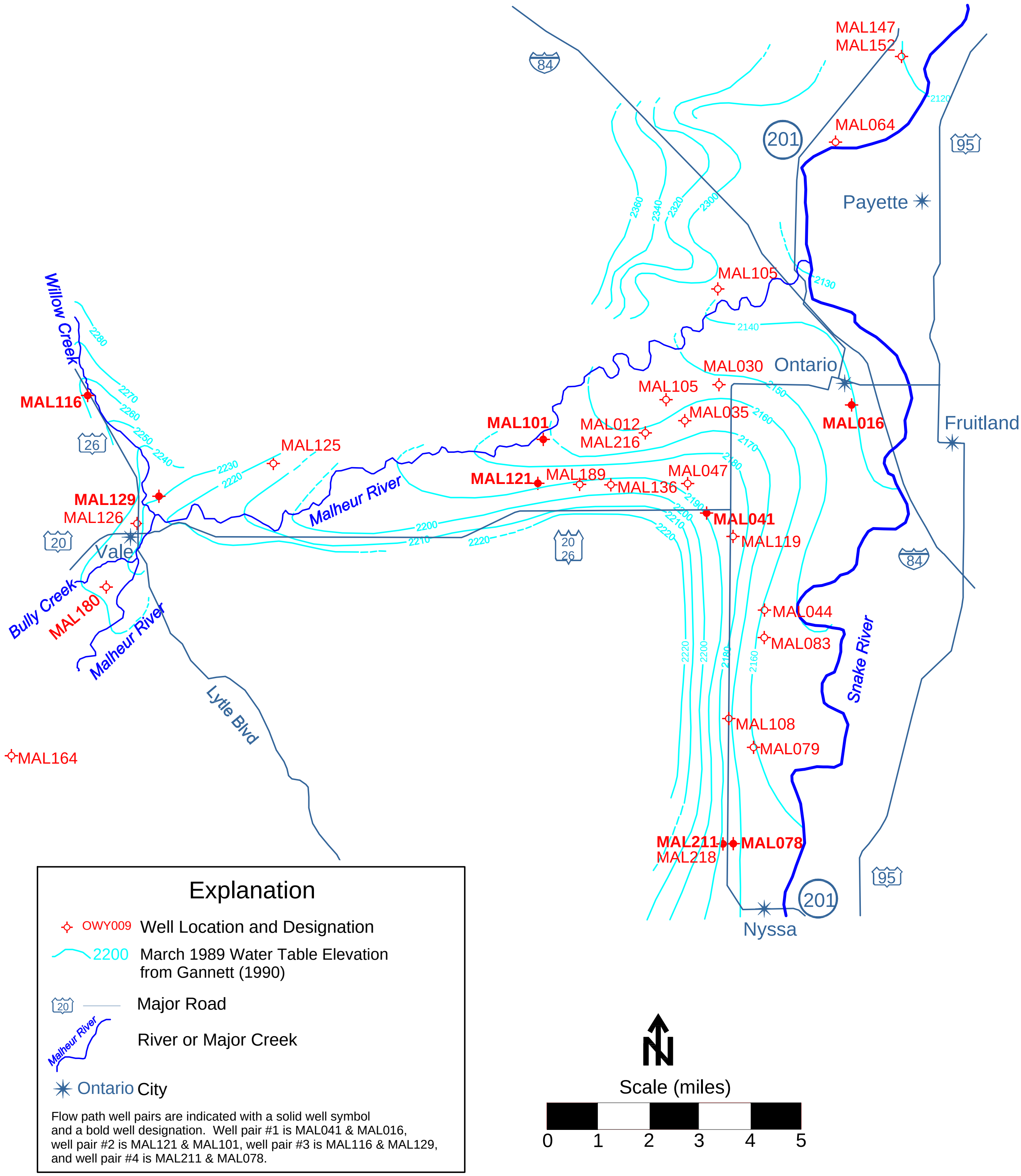
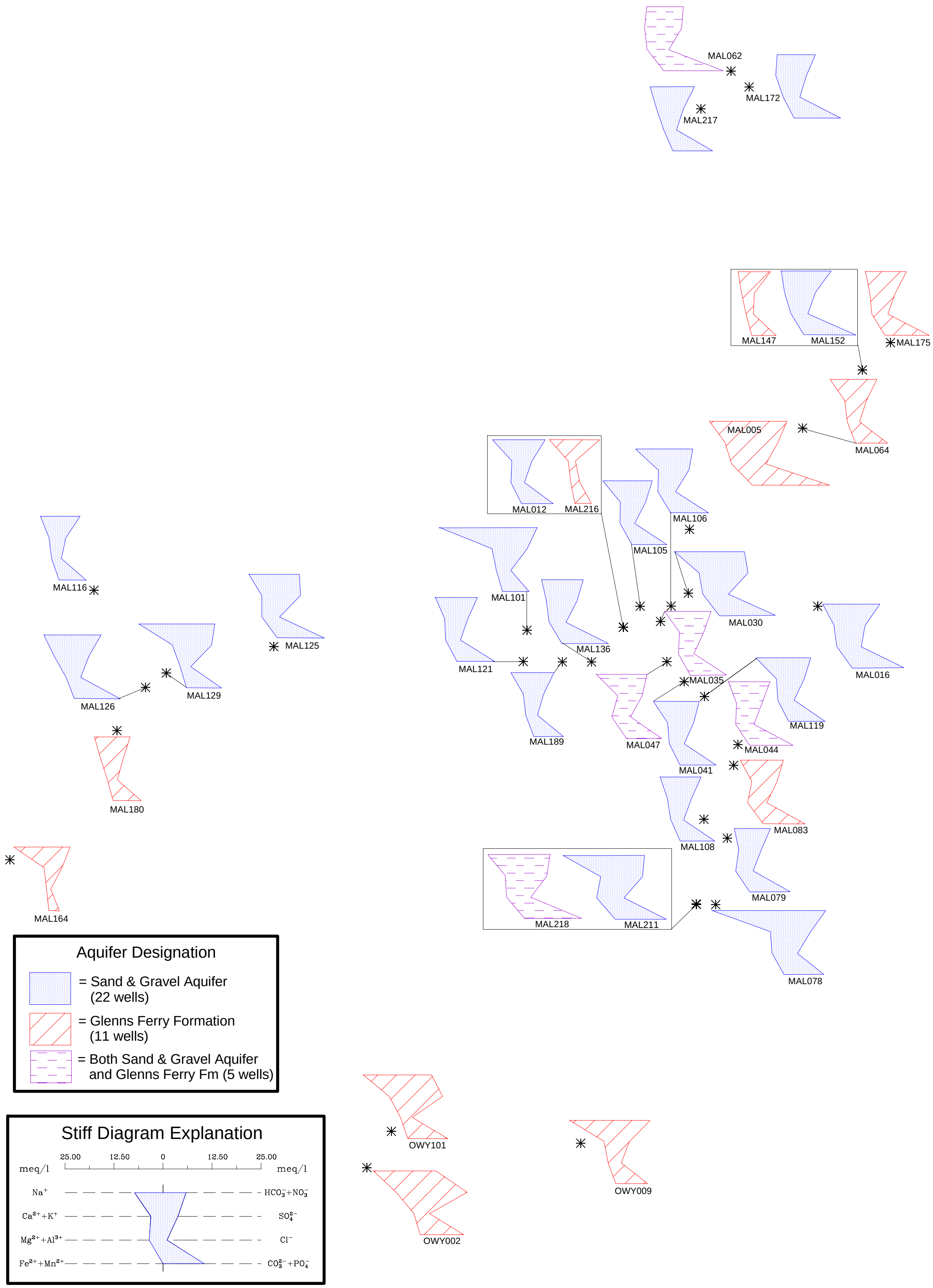


Figure 4-1
Location of Flow Path Well Pairs
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft wellpair.srf

Figure 5-1
Stiff Diagrams Showing General Water Quality of Aquifers
Northern Malheur County GWMA Trend Analysis Report



Note: There are 3 well nests in the network: MAL211 & MAL218, MAL012 & MAL216, and MAL147 & MAL152. Well nests are enclosed by a box.

e: malheur stiffs in color.srf

Figure 5-2
Piper Diagram Showing Representative Water Quality Samples
Northern Malheur County GWMA Trend Analysis Report

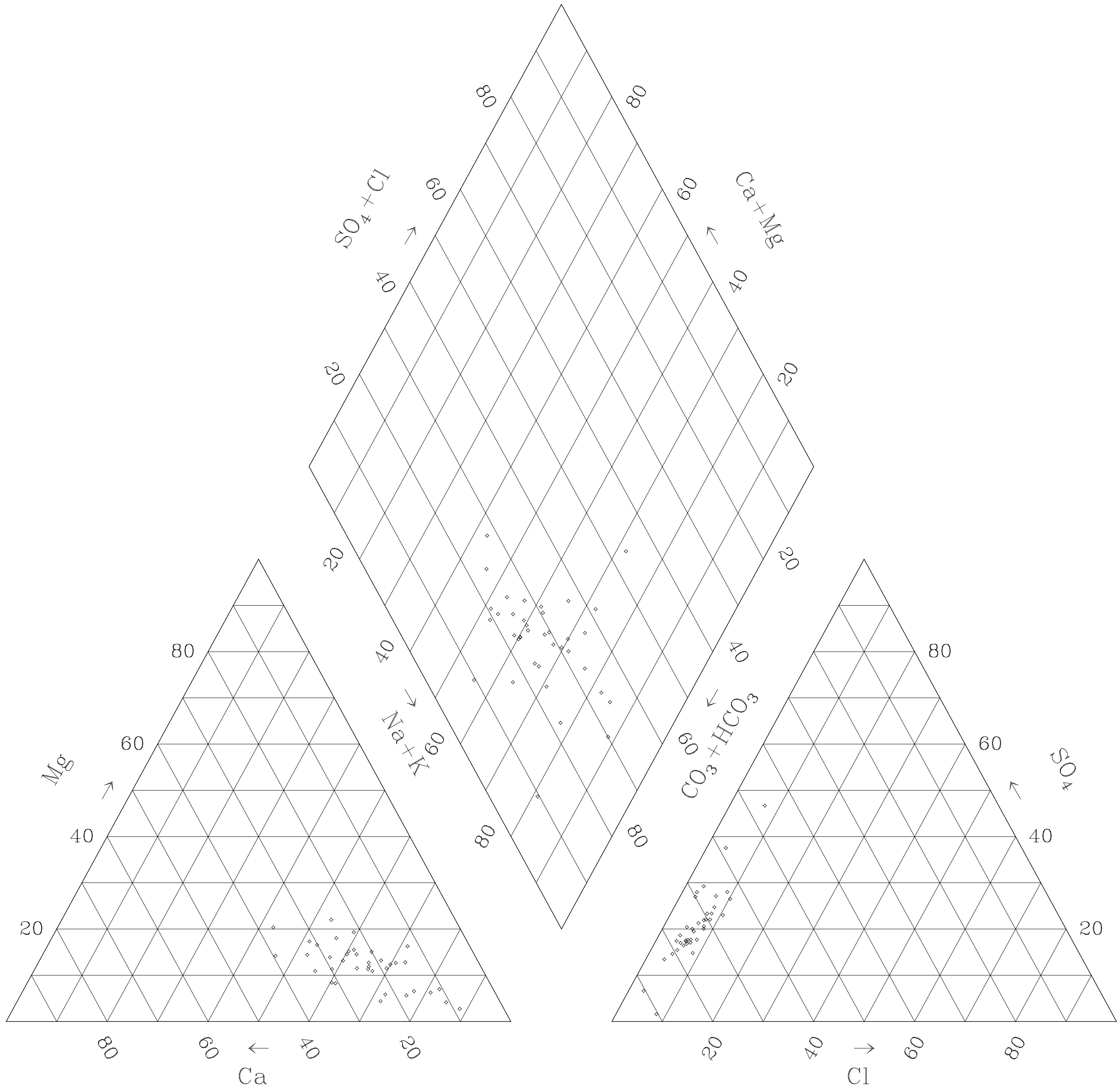
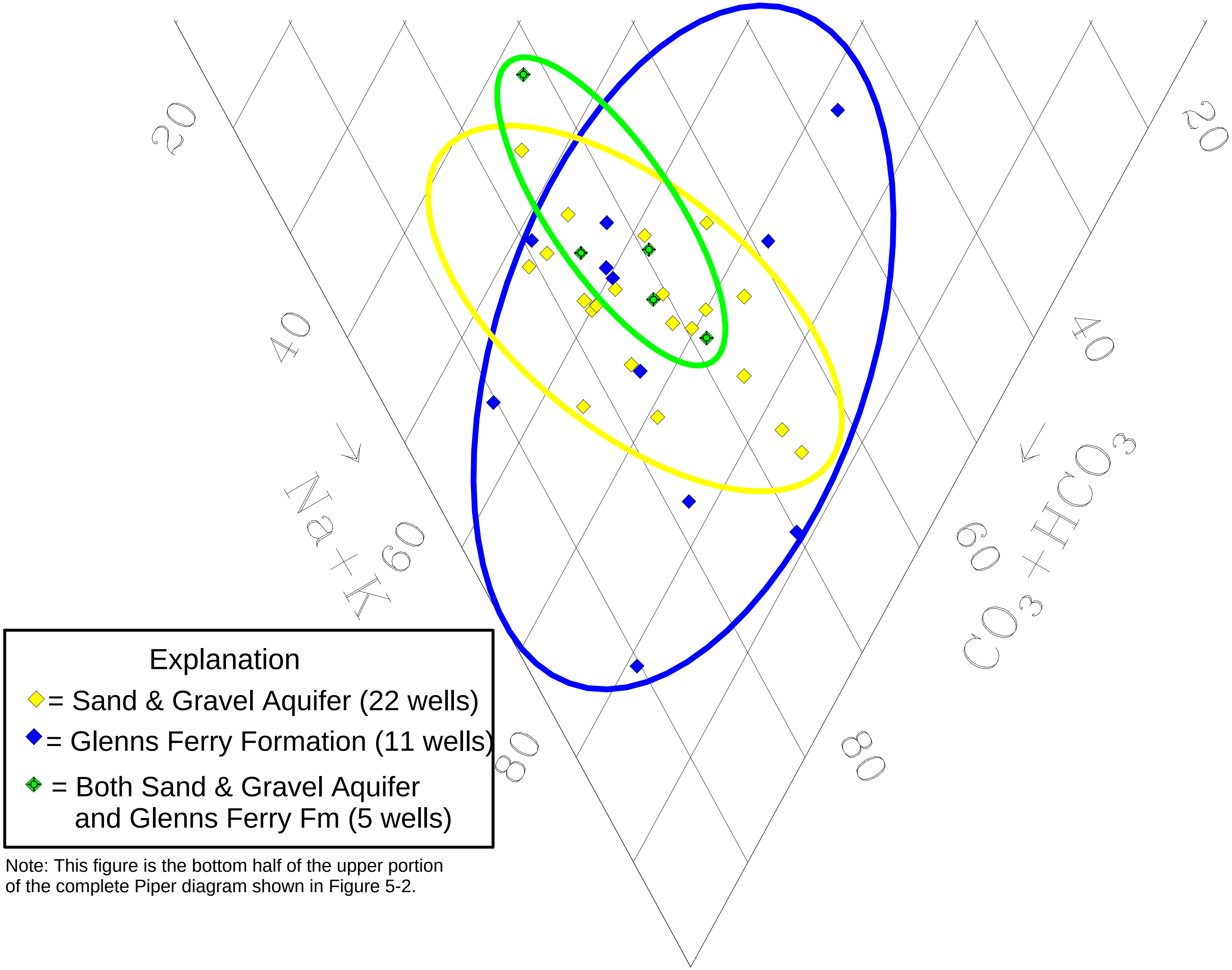
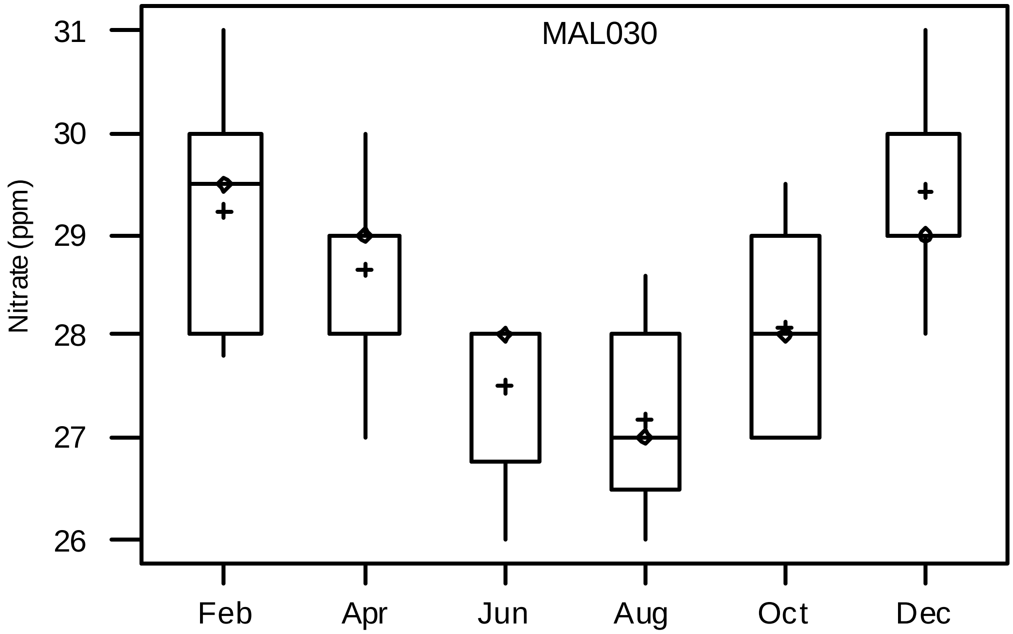


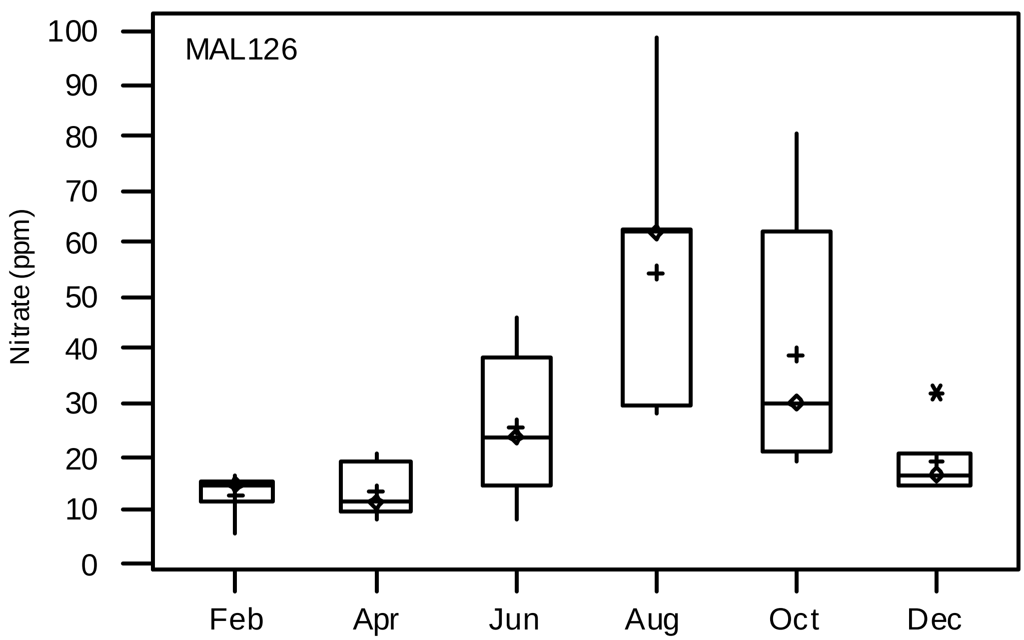
Figure 5-3
Piper Diagram Showing General Water Quality of Aquifers
Northern Malheur County GWMA Trend Analysis Report



Note: This figure is the bottom half of the upper portion of the complete Piper diagram shown in Figure 5-2.

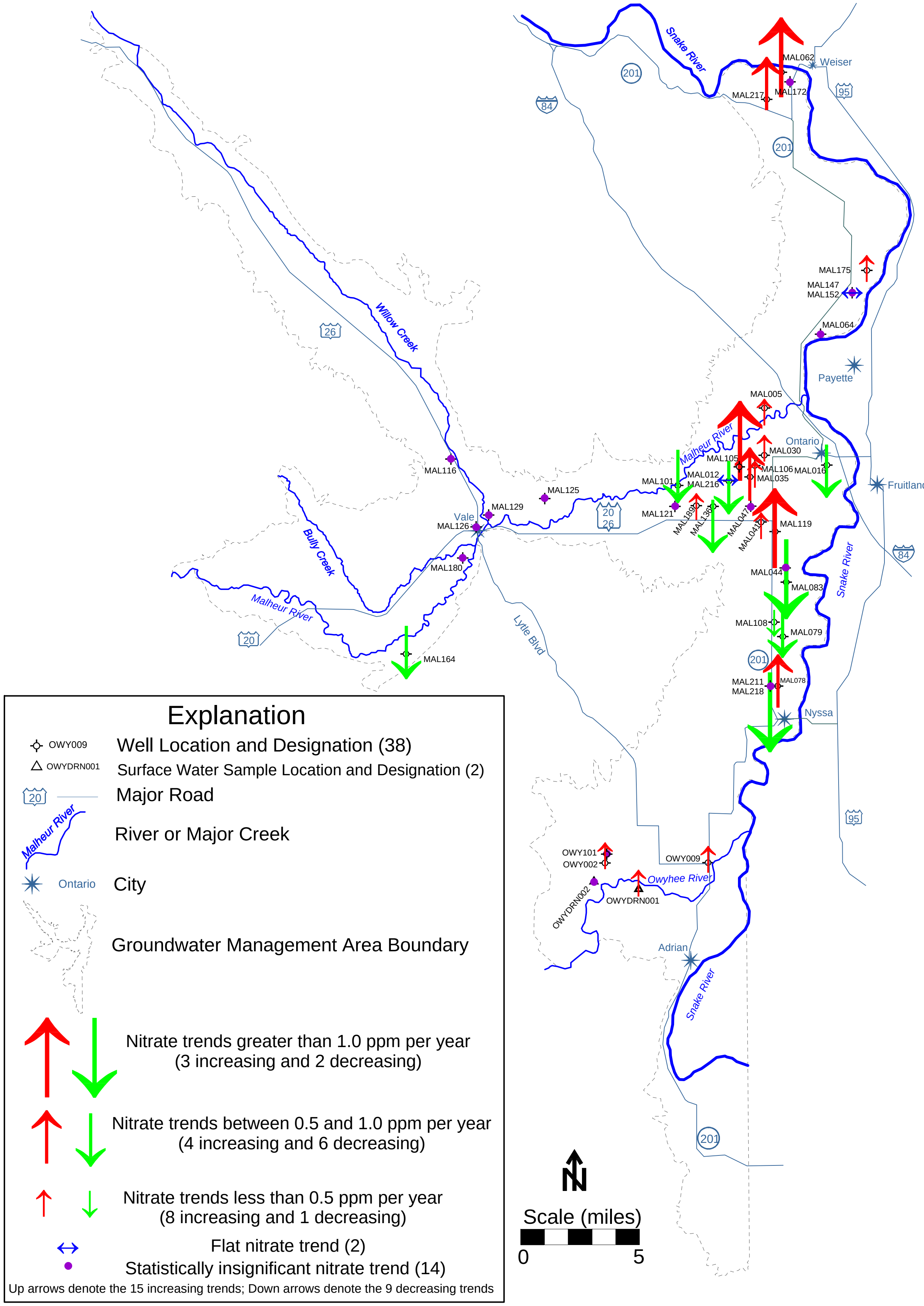
Figure 5-4
Box Plots Illustrating Seasonality
Northern Malheur County GWMA Trend Analysis Report





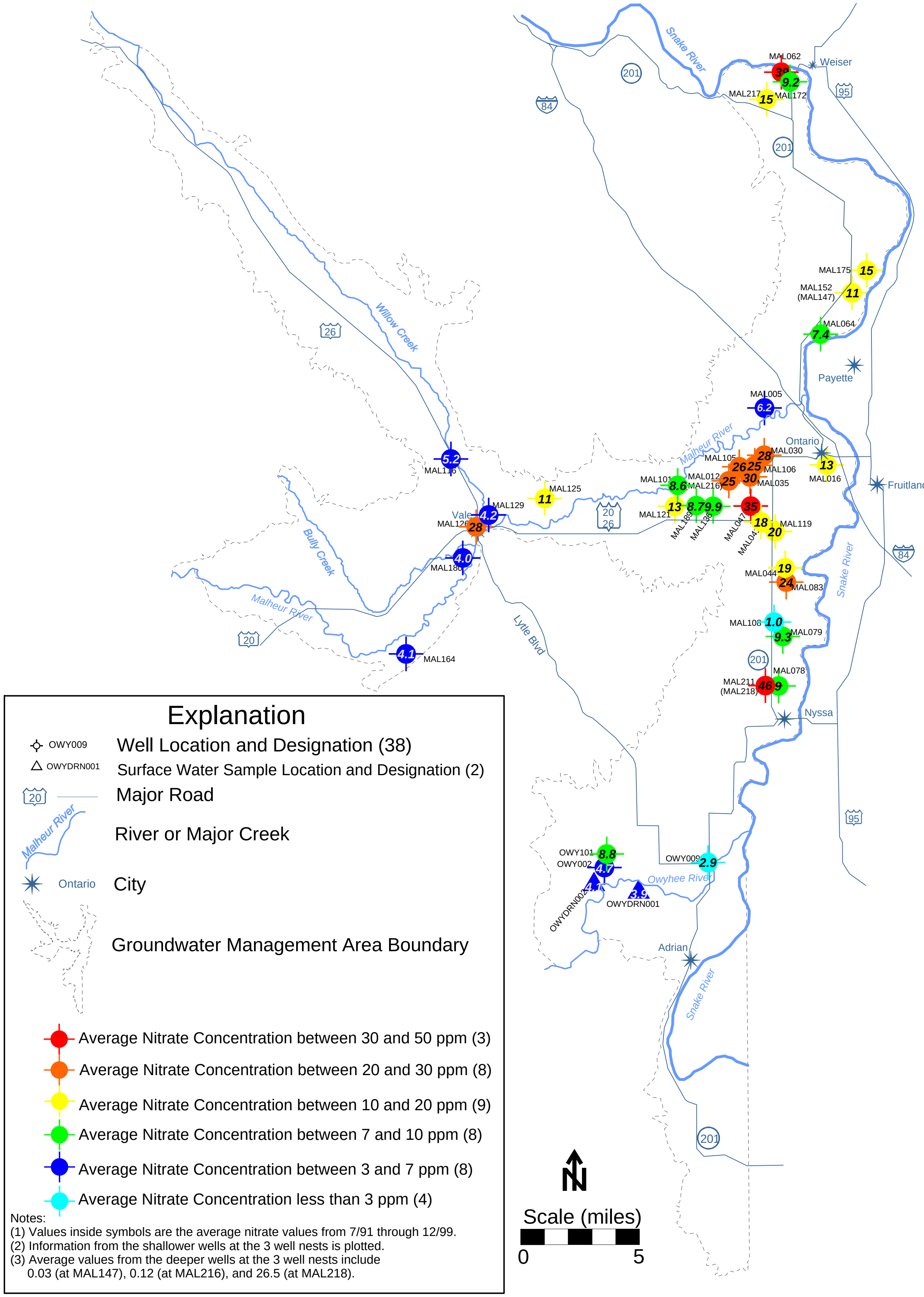
Boxplot Explanation:
The lower limit of the box is the 25th percentile (i.e., 25% of the data is less than this value).
The upper limit of the box is the 75th percentile. The height of the box is the interquartile range (IQR).
A line with a diamond on it drawn across the box indicates the median value. A plus denotes the mean value.
Heights of the two box halves depict the skewness (e.g., if the top half is larger the data is positively skewed).
Vertical lines are drawn from the top and bottom of the box to the farthest data points within 1.5 times the IQR.
Any data points beyond this distance are plotted individually with an asterisk.

Figure 5-5
Nitrate Trends at Individual Wells
Northern Malheur County GWMA Trend Analysis Report



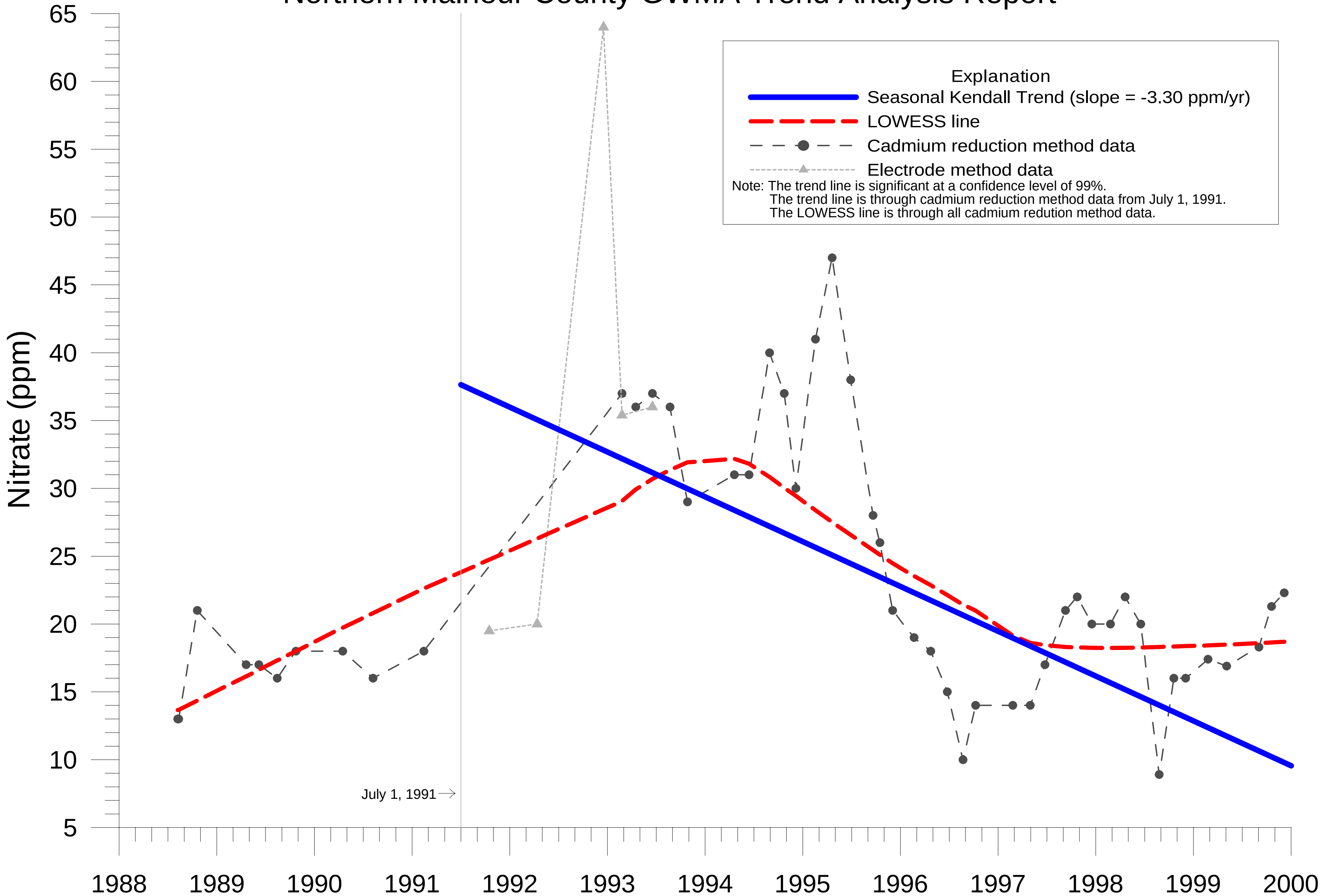
e: malheur 3rddraft no3trnd.srf

Figure 5-6
Average Nitrate Concentrations at Individual Wells
Northern Malheur County GWMA Trend Analysis Report



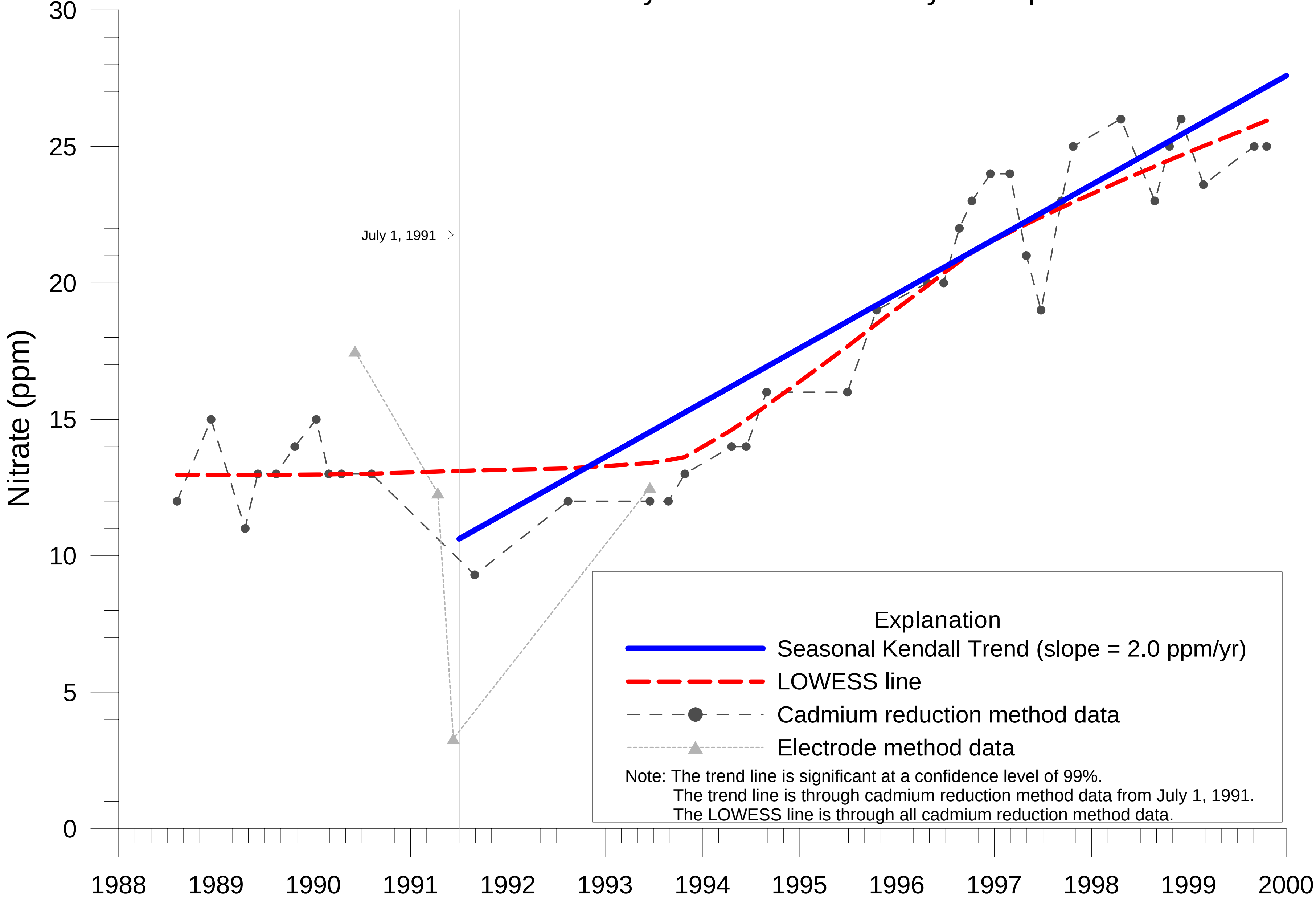
e: malheur 3rddraft no3avg.srf

Figure 5-7
Nitrate Trend at Well MAL083
Northern Malheur County GWMA Trend Analysis Report



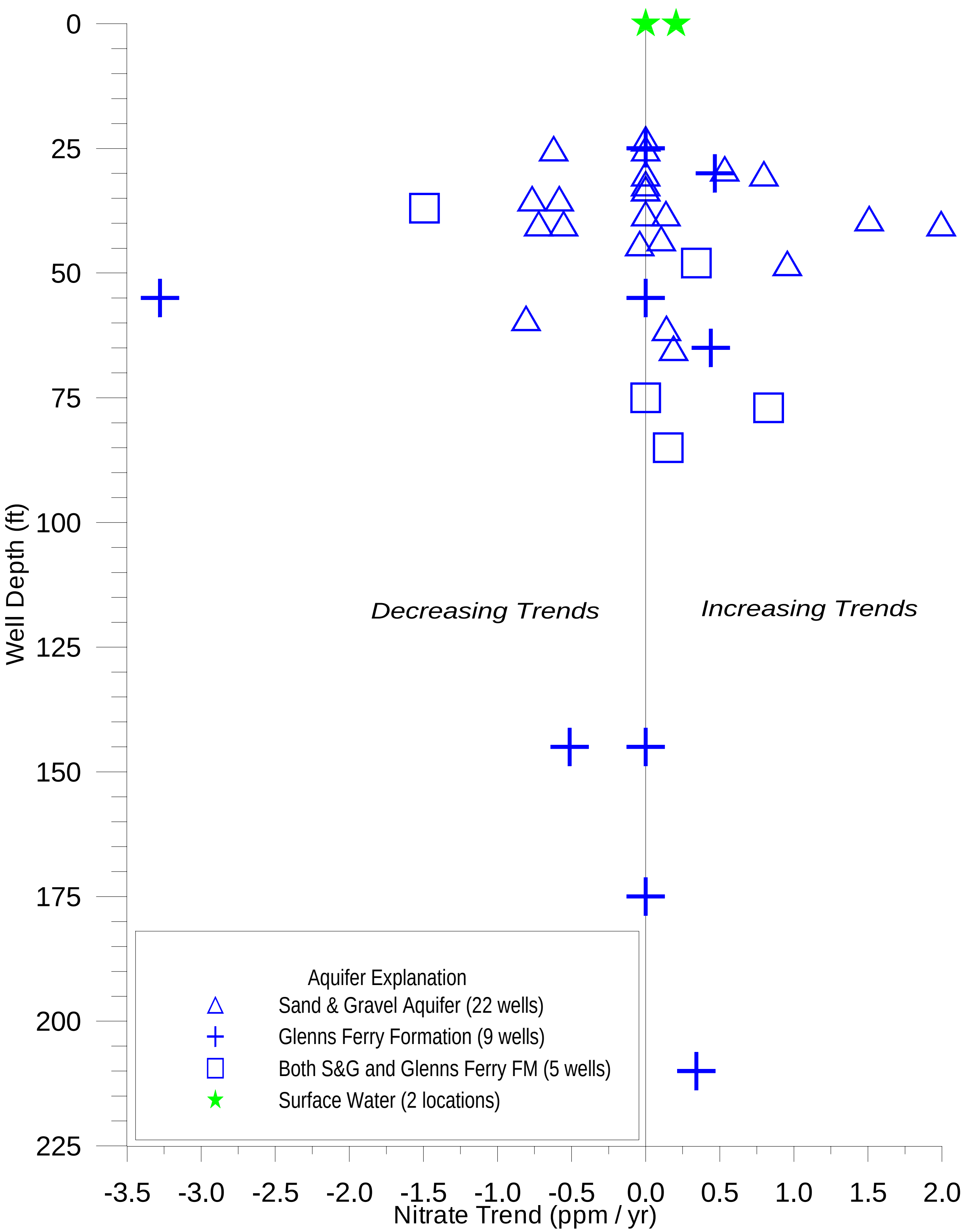
e: malheur 3rddraft mal083n$.grf

Figure 5-8
Nitrate Trend at Well MAL119
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft mal119n$.grf

Figure 5-9
Nitrate Trend vs. Well Depth
Northern Malheur County GWMA Trend Analysis Report



Notes:
(1) Two wells of unknown depth are assumed to be S&G AQ wells and are not plotted.
One has a slight increasing trend (0.04 ppm/yr) and the other has no significant trend.
(2) Wells with no significant trend are plotted with a 0.0 ppm/yr trend.

e: malheur 3rddraft dpthtrnd.grf

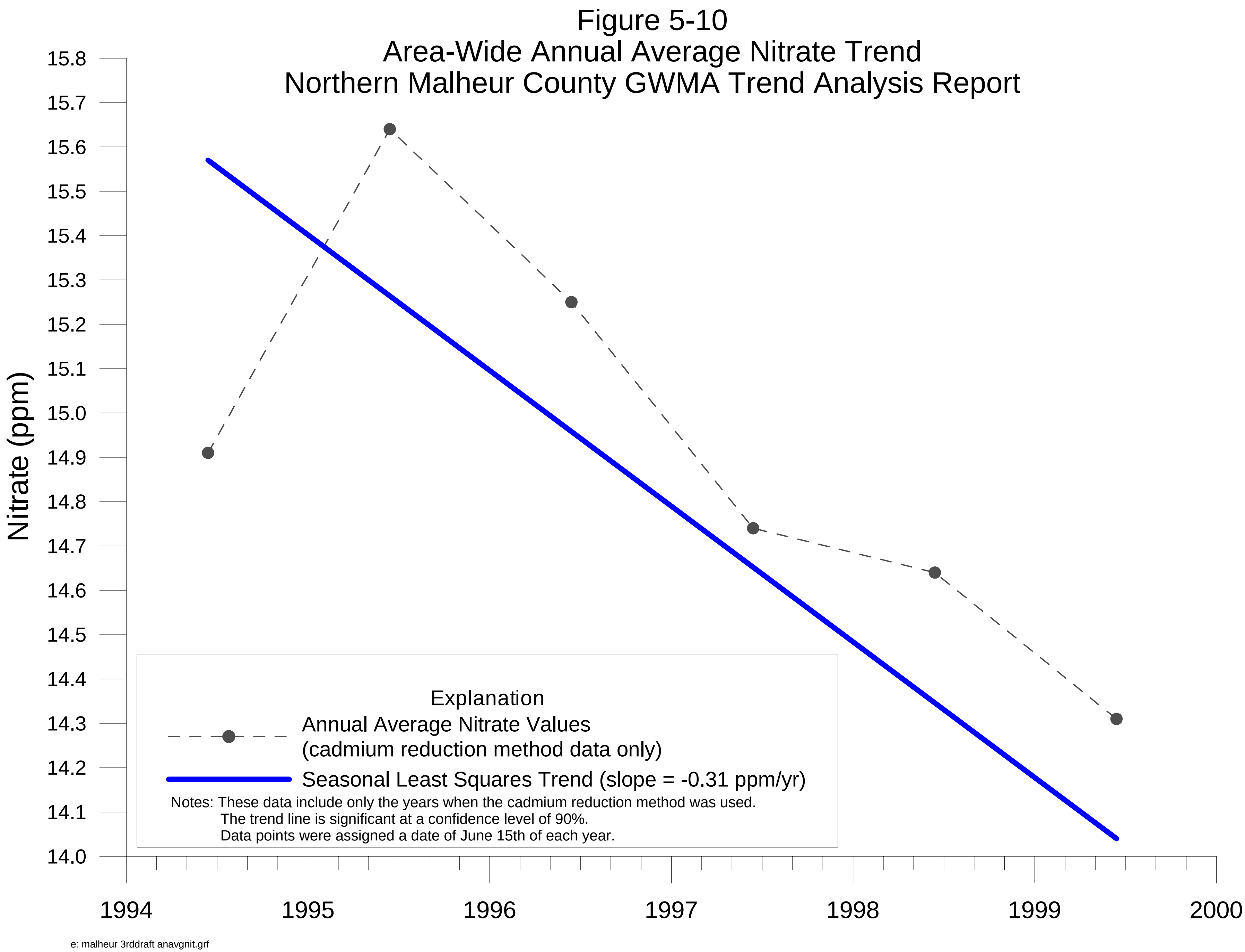
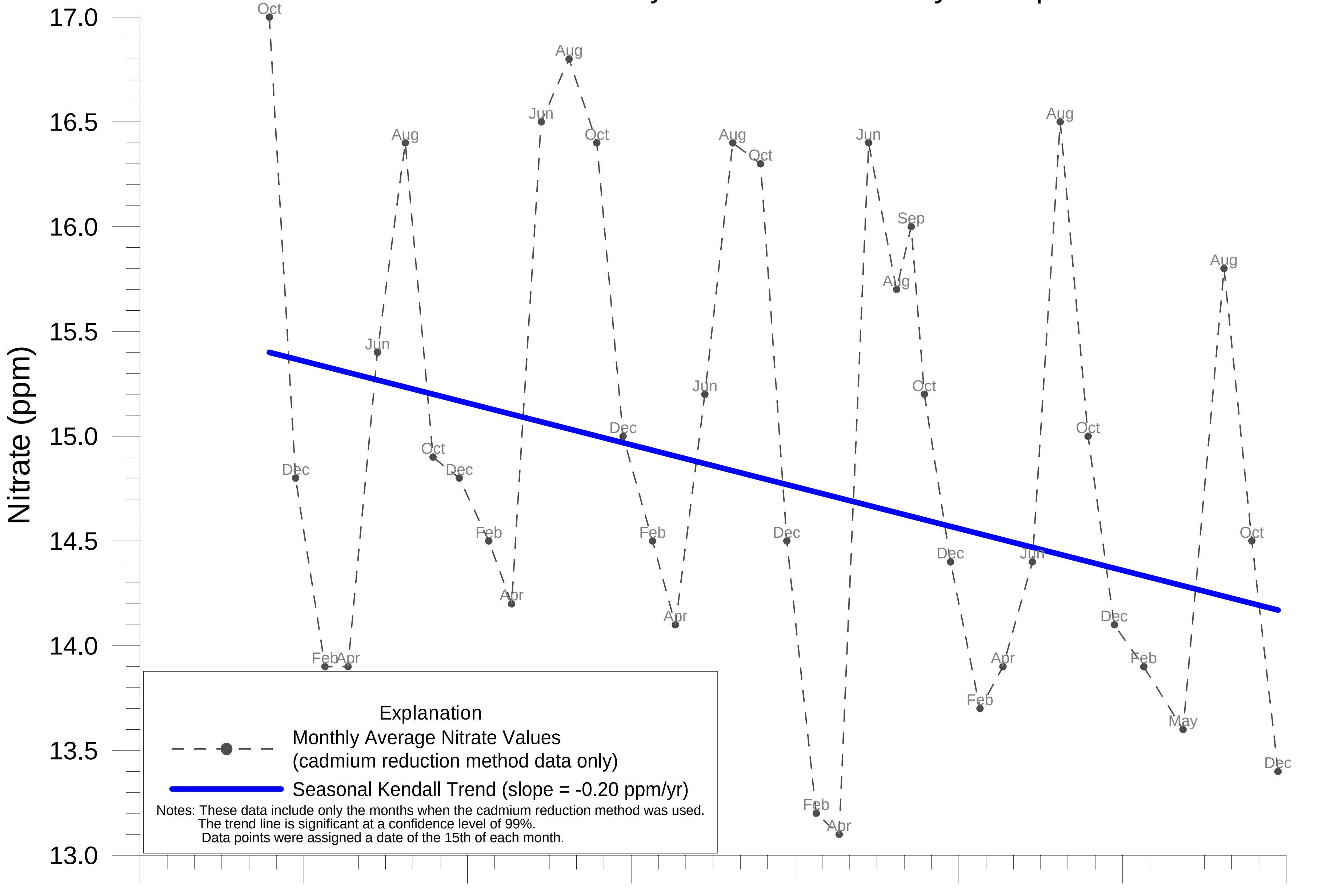


Figure 5-10
Area-Wide Annual Average Nitrate Trend
Northern Malheur County GWMA Trend Analysis Report
Nitrate (ppm)
15.8
15.7
15.6
15.5
15.4
15.3
15.2
15.1
15.0
14.9
14.8
14.7
14.6
14.5
14.4
14.3
14.2
14.1
14.0
1994
1995
1996
1997
1998
1999
2000
Explanation
Annual Average Nitrate Values
(cadmium reduction method data only)
Seasonal Least Squares Trend (slope = -0.31 ppm/yr)
Notes: These data include only the years when the cadmium reduction method was used.
The trend line is significant at a confidence level of 90%.
Data points were assigned a date of June 15th of each year.
e: malheur 3rddraft anavgnit.grf

Figure 5-11
Area-Wide Monthly Average Nitrate Trend
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft moavgnit.grf

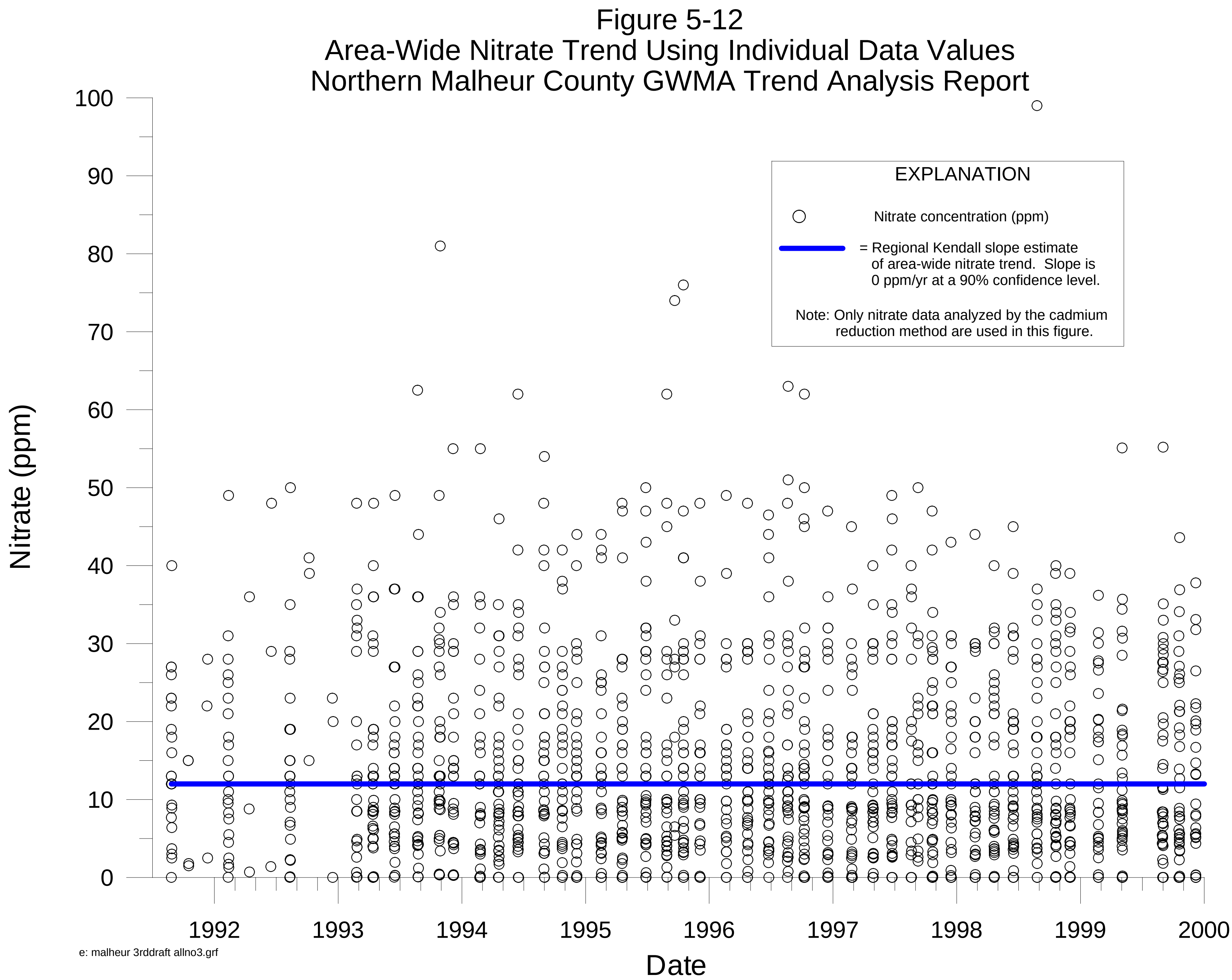


Figure 5-12
Area-Wide Nitrate Trend Using Individual Data Values
Northern Malheur County GWMA Trend Analysis Report
EXPLANATION
Nitrate concentration (ppm)
= Regional Kendall slope estimate of area-wide nitrate trend. Slope is 0 ppm/yr at a 90% confidence level.
Note: Only nitrate data analyzed by the cadmium reduction method are used in this figure.
Nitrate (ppm)
0
10
20
30
40
50
60
70
80
90
100
1992
1993
1994
1995
1996
1997
1998
1999
2000
Date
e: malheur 3rddraft allno3.grf

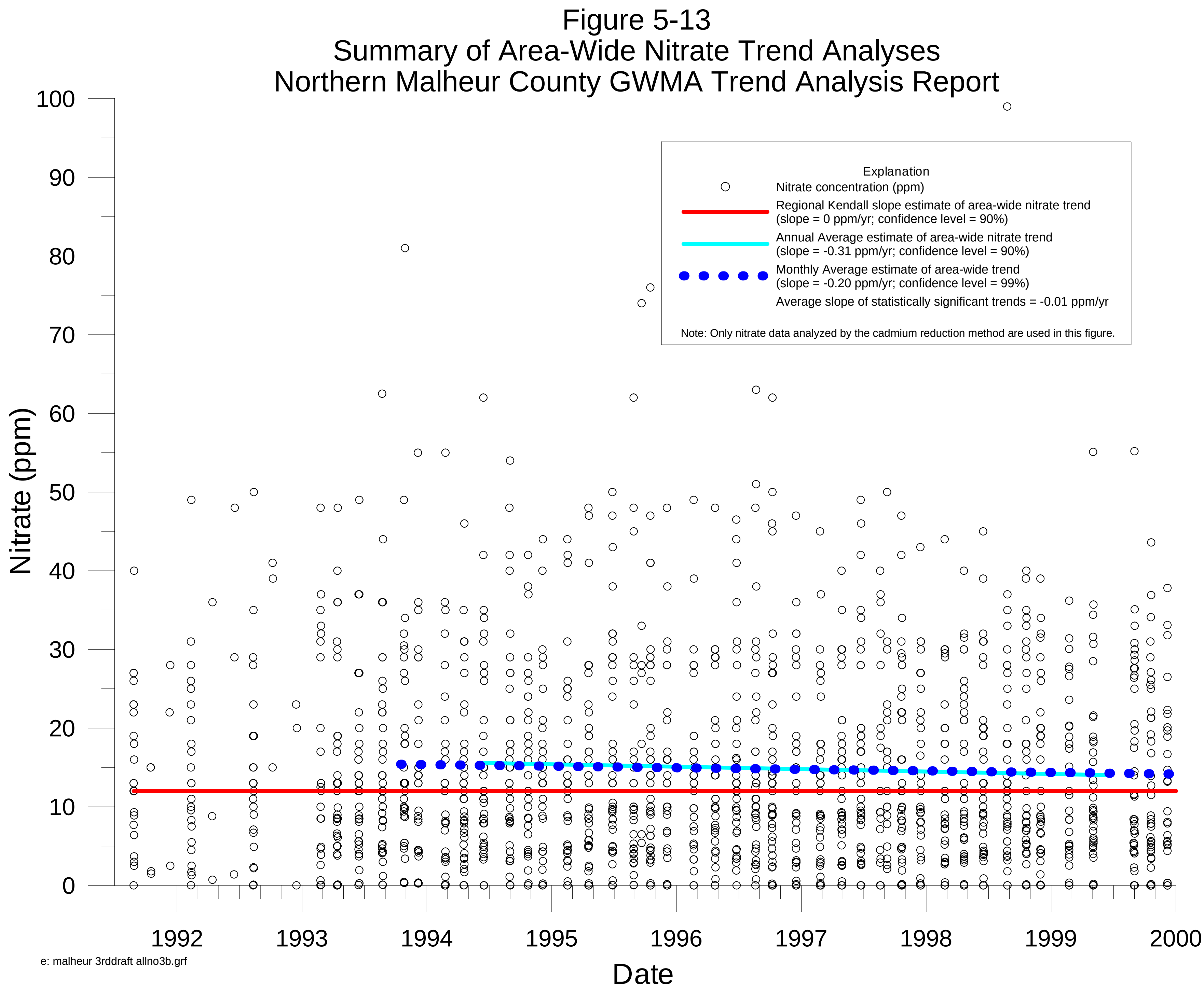
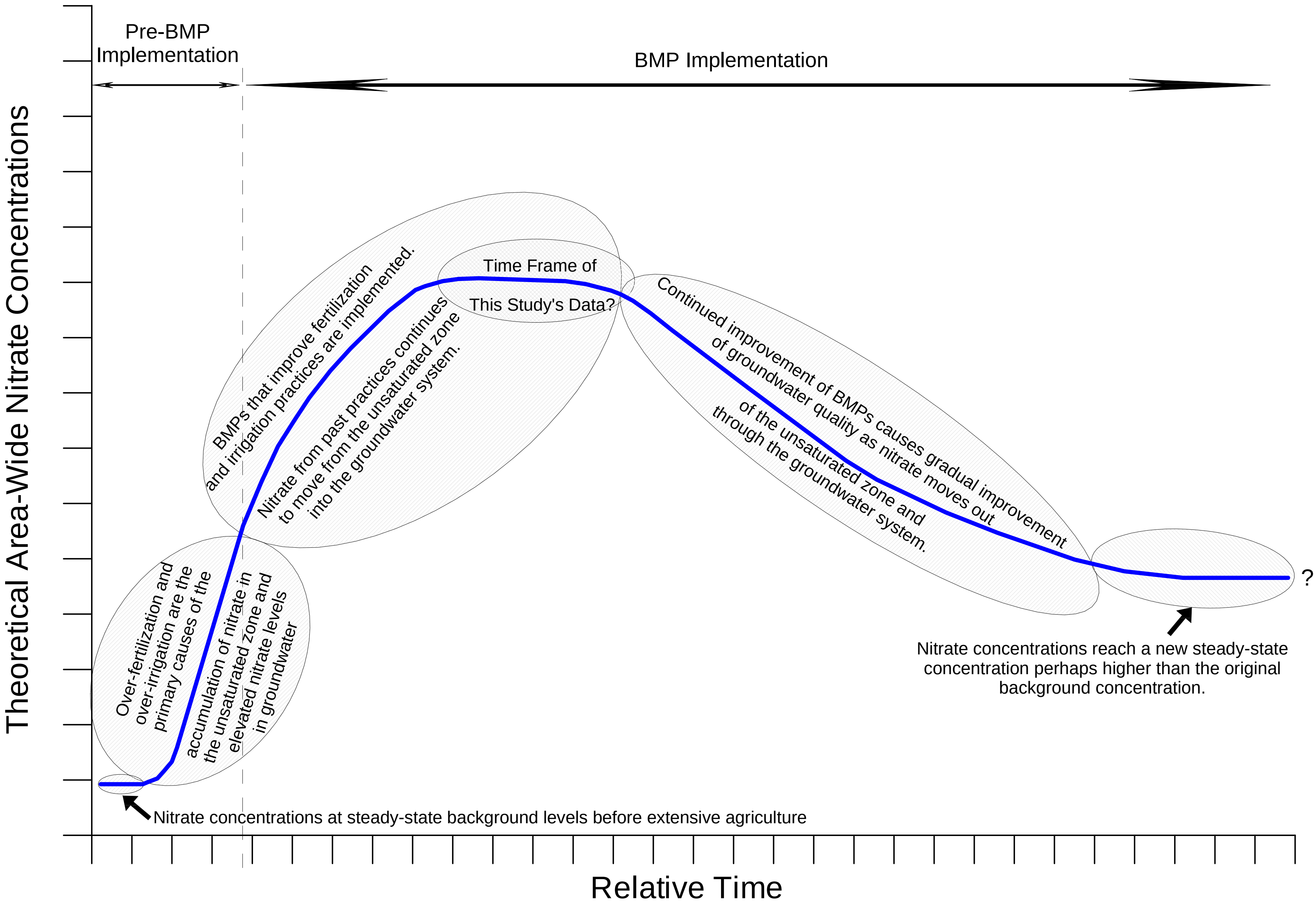


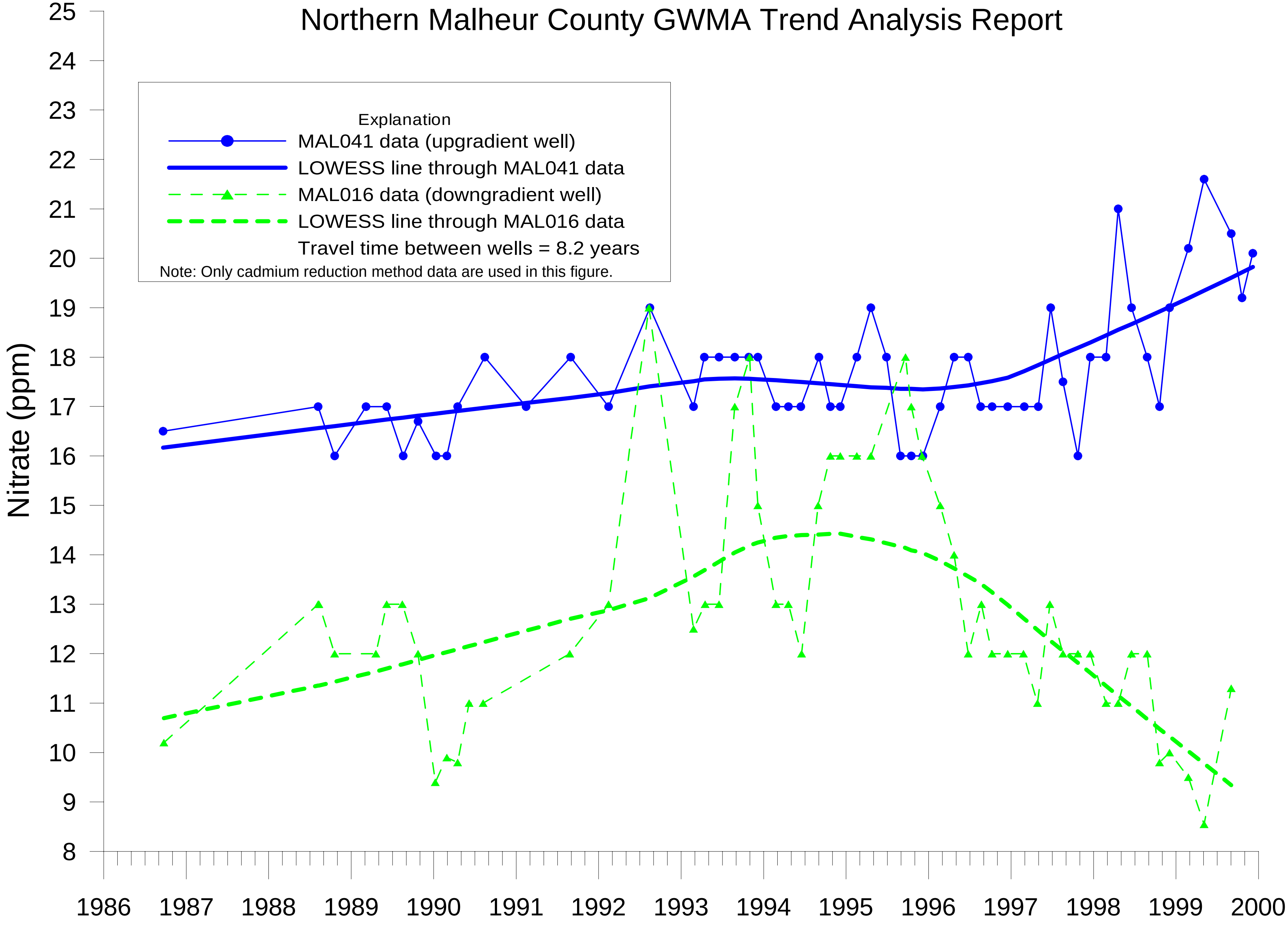
Figure 5-13
Summary of Area-Wide Nitrate Trend Analyses
Northern Malheur County GWMA Trend Analysis Report
Nitrate (ppm)
0
10
20
30
40
50
60
70
80
90
100
Date
1992
1993
1994
1995
1996
1997
1998
1999
2000
Explanation
Nitrate concentration (ppm)
Regional Kendall slope estimate of area-wide nitrate trend
(slope = 0 ppm/yr; confidence level = 90%)
Annual Average estimate of area-wide nitrate trend
(slope = -0.31 ppm/yr; confidence level = 90%)
Monthly Average estimate of area-wide trend
(slope = -0.20 ppm/yr; confidence level = 99%)
Average slope of statistically significant trends = -0.01 ppm/yr
Note: Only nitrate data analyzed by the cadmium reduction method are used in this figure.
e: malheur 3rddraft allno3b.grf

Figure 5-14
A Conceptual Model of Area-Wide Nitrate Trend
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft model.grf

Figure 5-15
Time Series Plot of Well Pair #1 Nitrate Values
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft pair1n$.grf

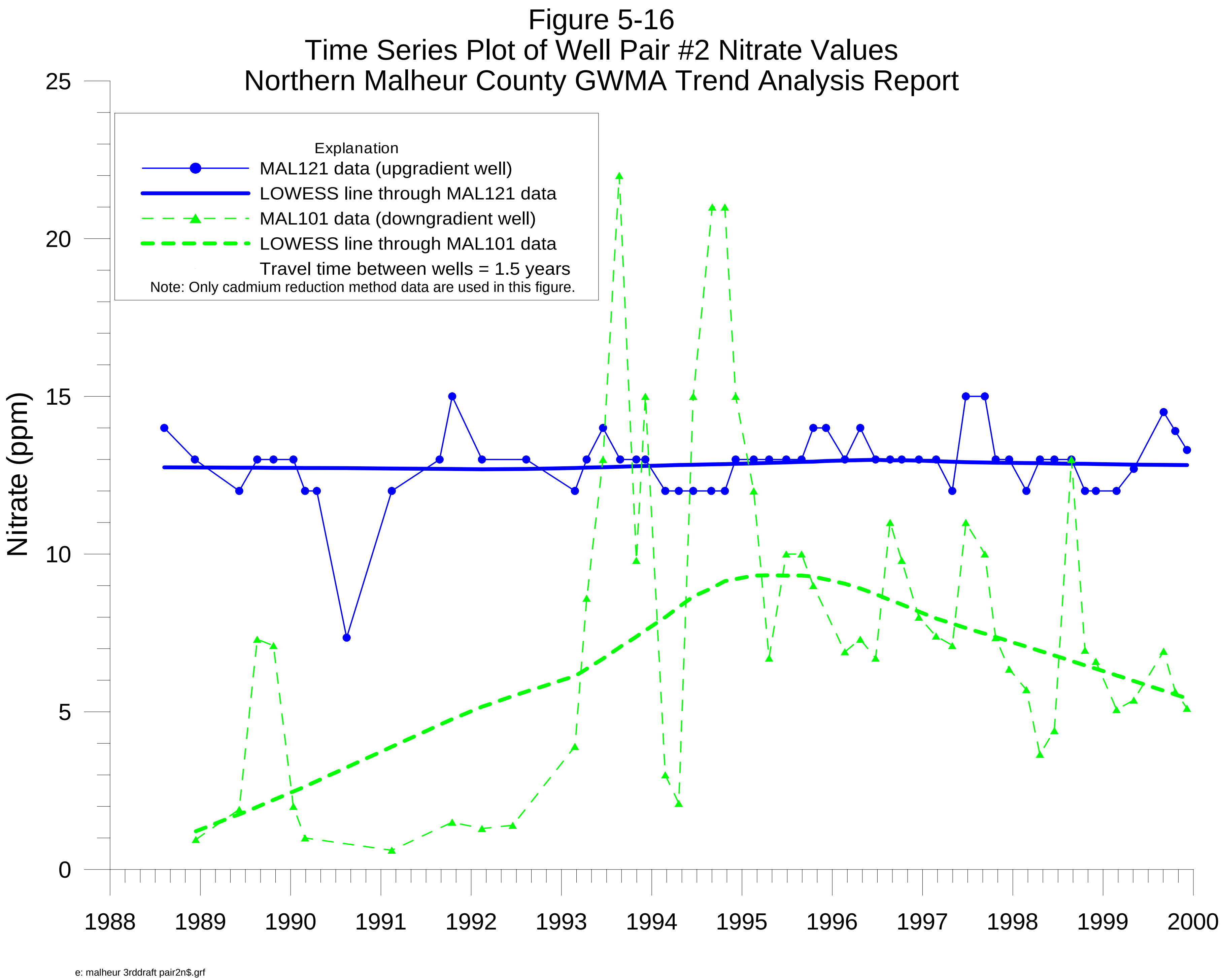
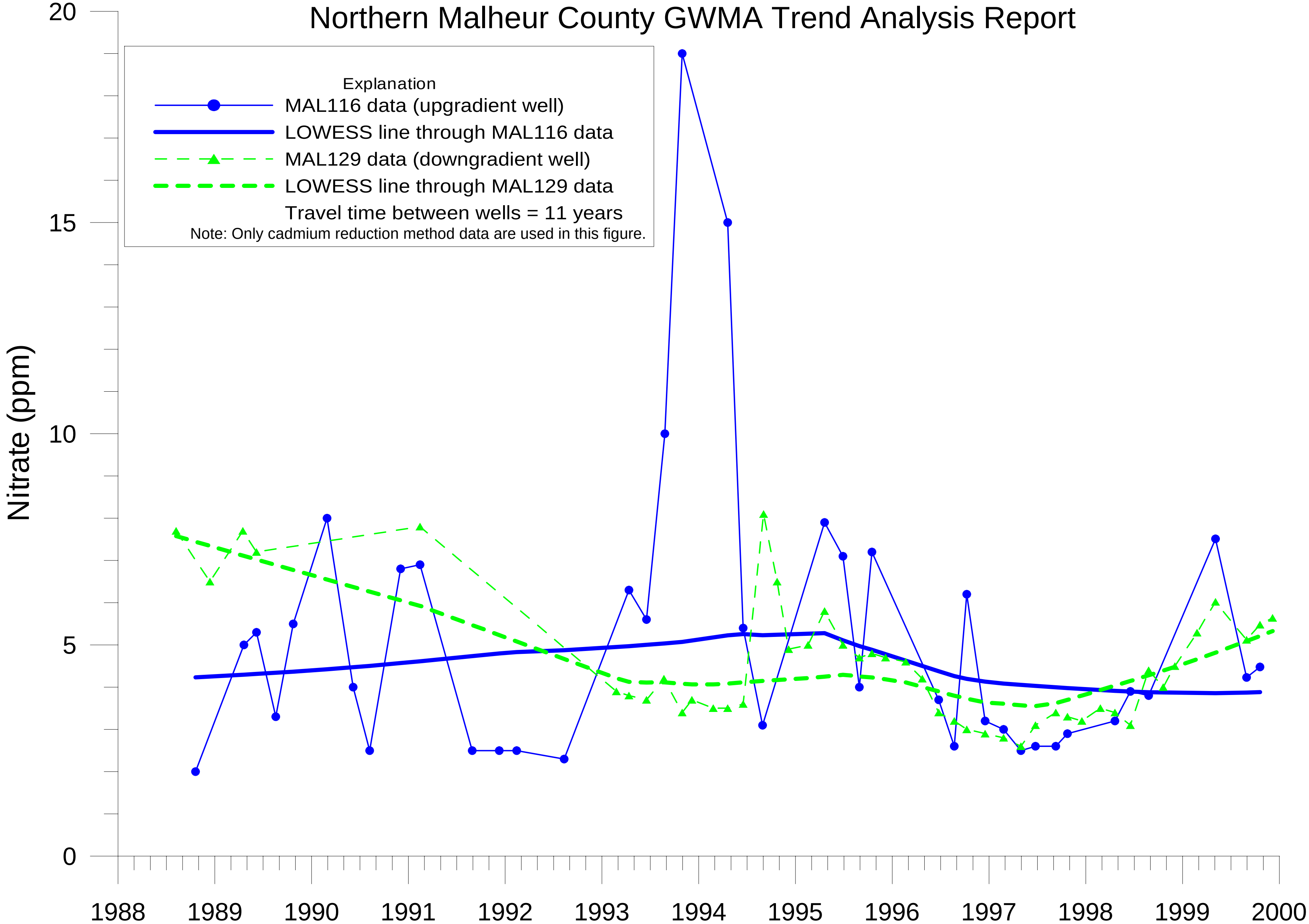


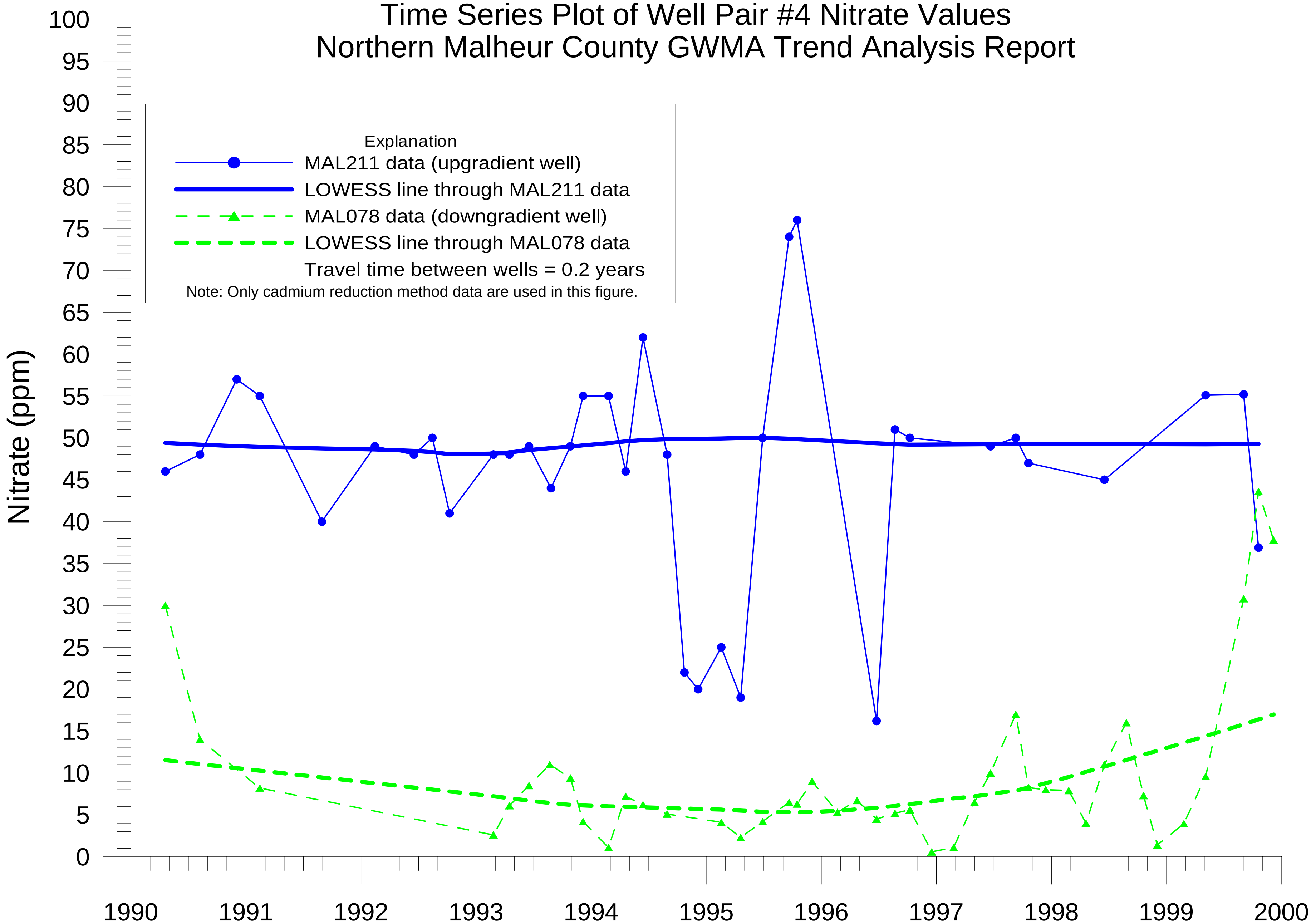
Figure 5-16
Time Series Plot of Well Pair #2 Nitrate Values
Northern Malheur County GWMA Trend Analysis Report
Explanation
MAL121 data (upgradient well)
LOWESS line through MAL121 data
MAL101 data (downgradient well)
LOWESS line through MAL101 data
Travel time between wells = 1.5 years
Note: Only cadmium reduction method data are used in this figure.
Nitrate (ppm)
0
5
10
15
20
25
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
e: malheur 3rddraft pair2n$.grf

Figure 5-17
Time Series Plot of Well Pair #3 Nitrate Values
Northern Malheur County GWMA Trend Analysis Report



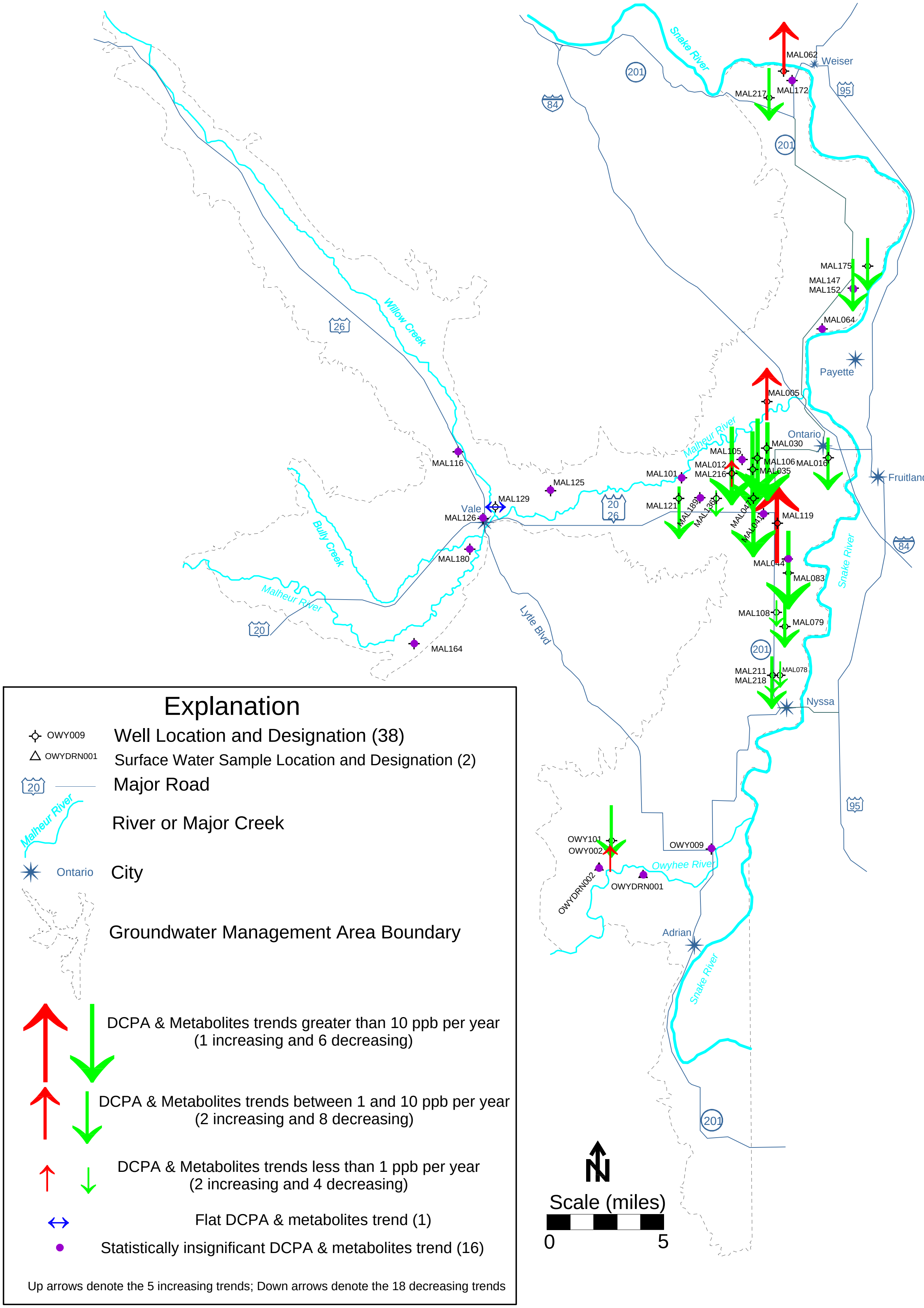
e: malheur 3rddraft pair3n$.grf

Figure 5-18
Time Series Plot of Well Pair #4 Nitrate Values
Northern Malheur County GWMA Trend Analysis Report



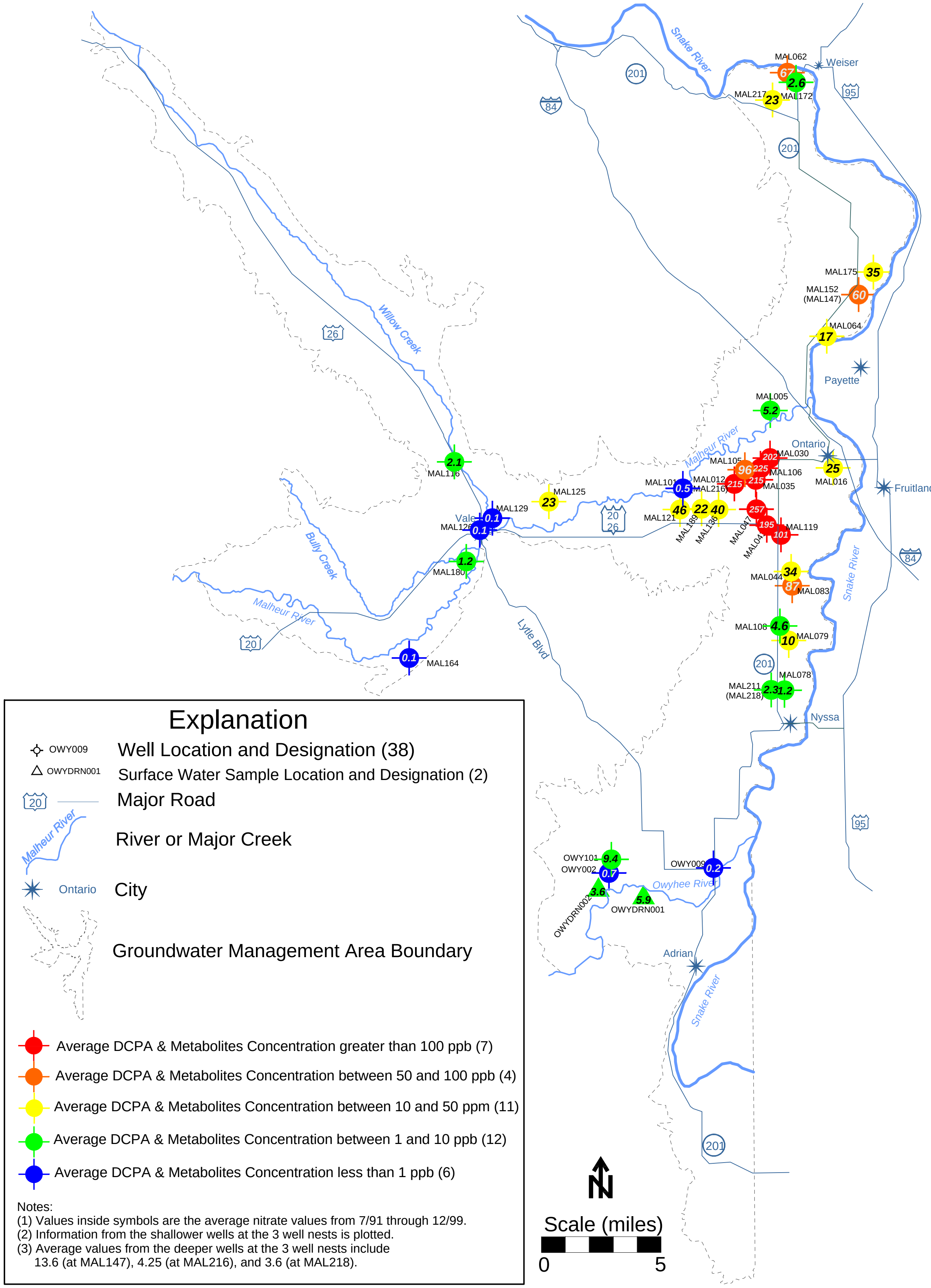
e: malheur 3rddraft pair4n$.grf

Figure 5-19
DCPA & Metabolites Trends
Northern Malheur County GWMA Trend Analysis Report



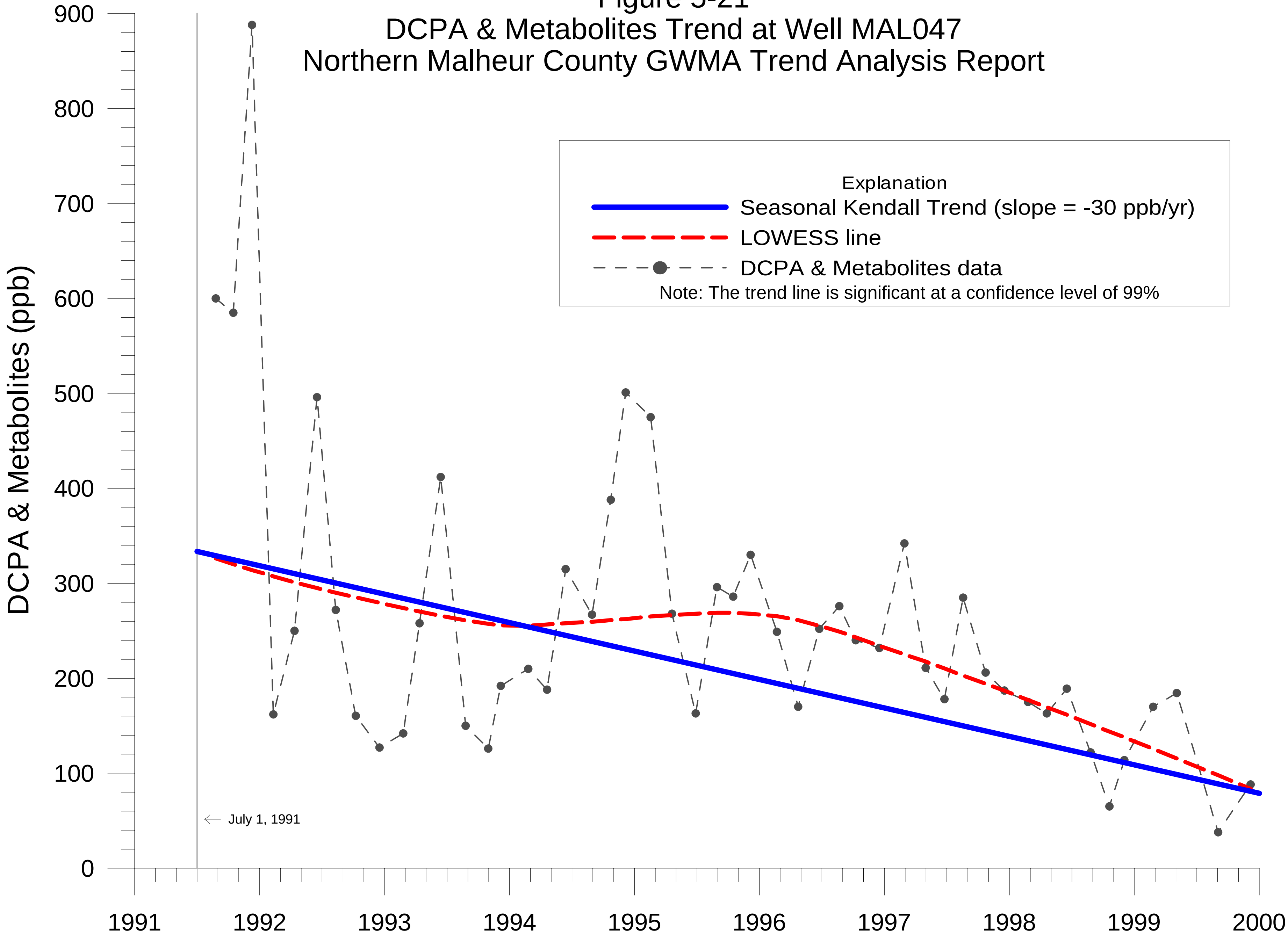
e: malheur 3rddraft dactrnd.srf

Figure 5-20
Average DCPA & Metabolites Concentrations
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft DCPAavg.srf

Figure 5-21
DCPA & Metabolites Trend at Well MAL047
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft mal047d$.grf

Figure 5-22
DCPA & Metabolites Trend at Well MAL119
Northern Malheur County GWMA Trend Analysis Report

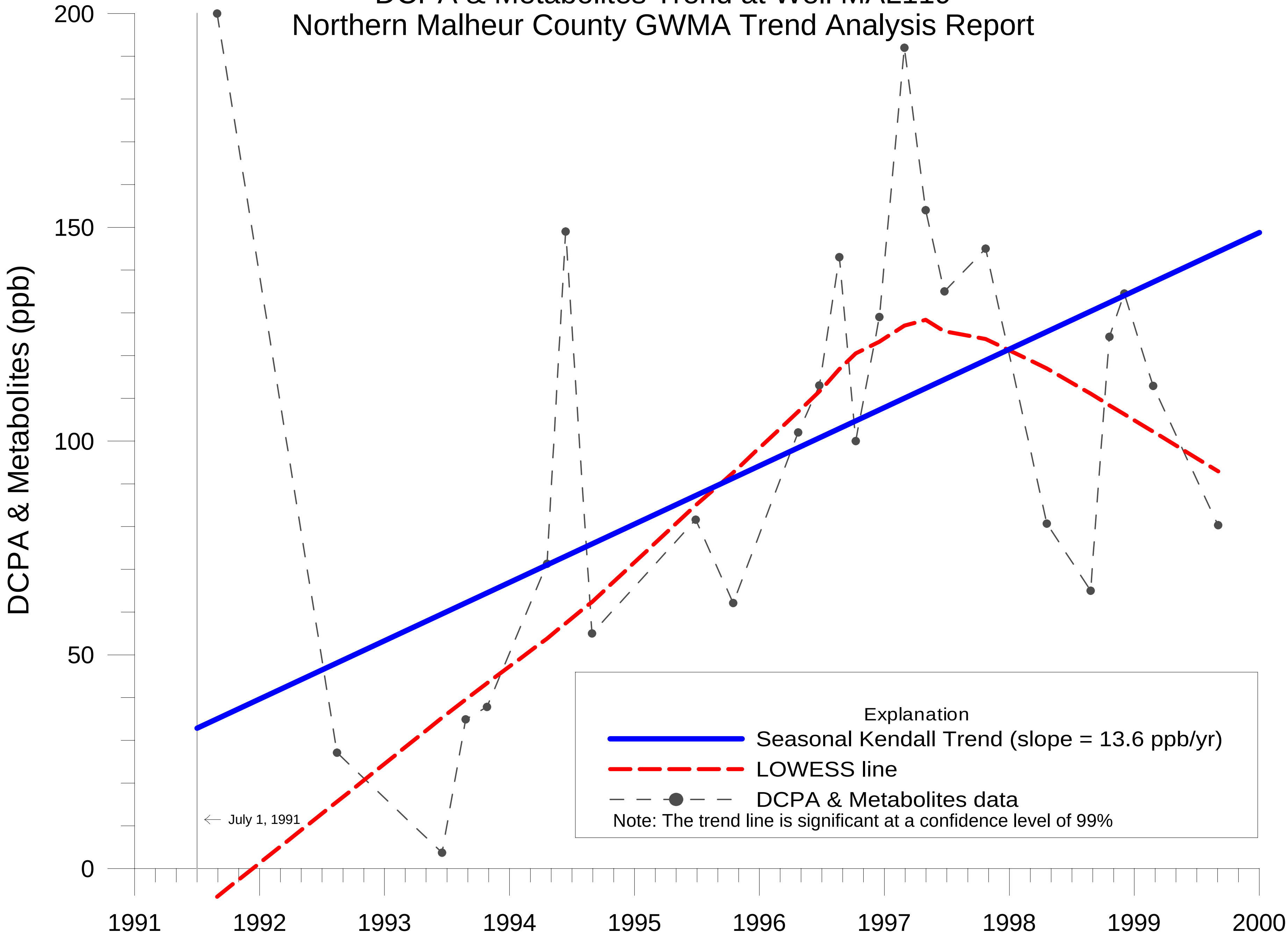
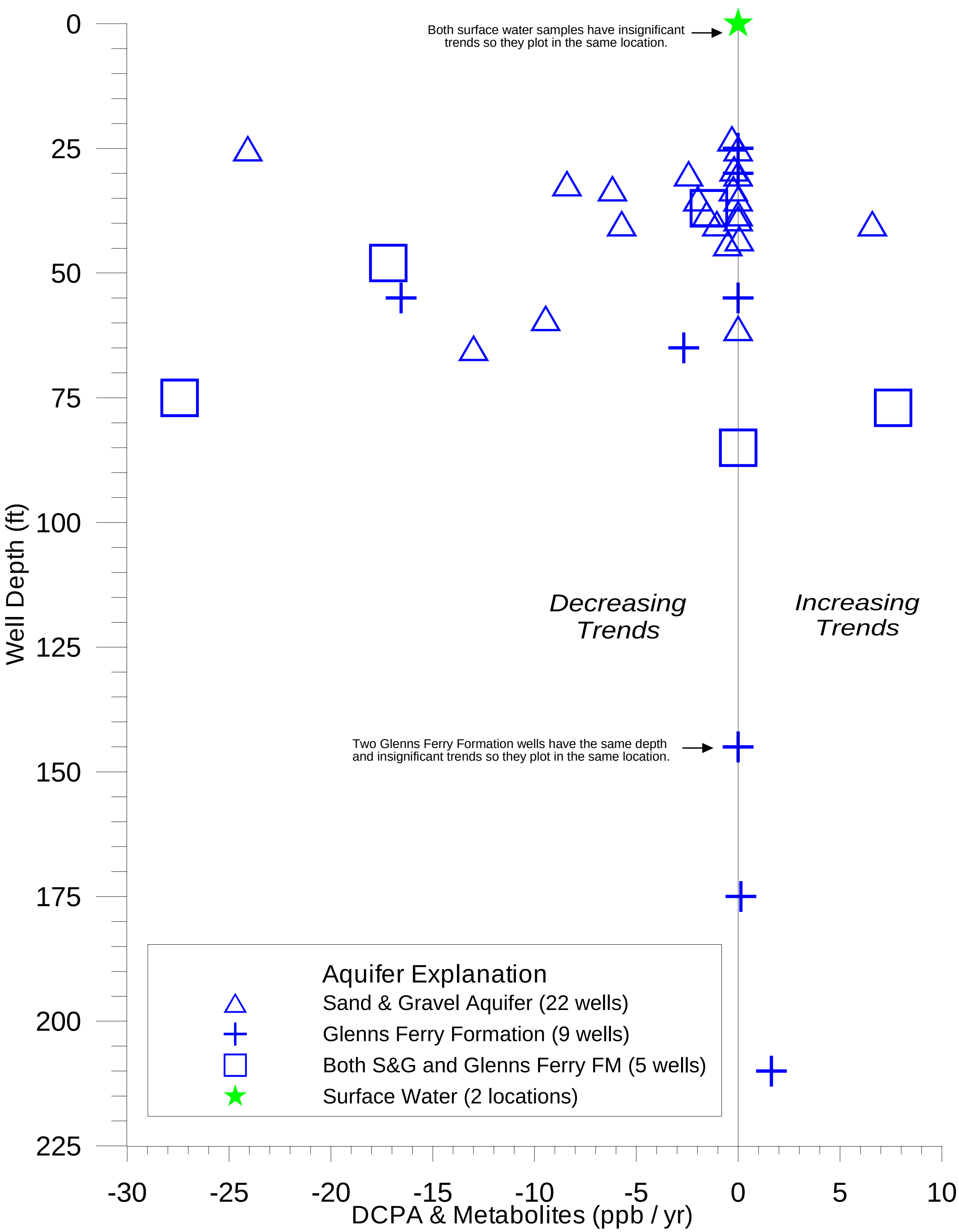


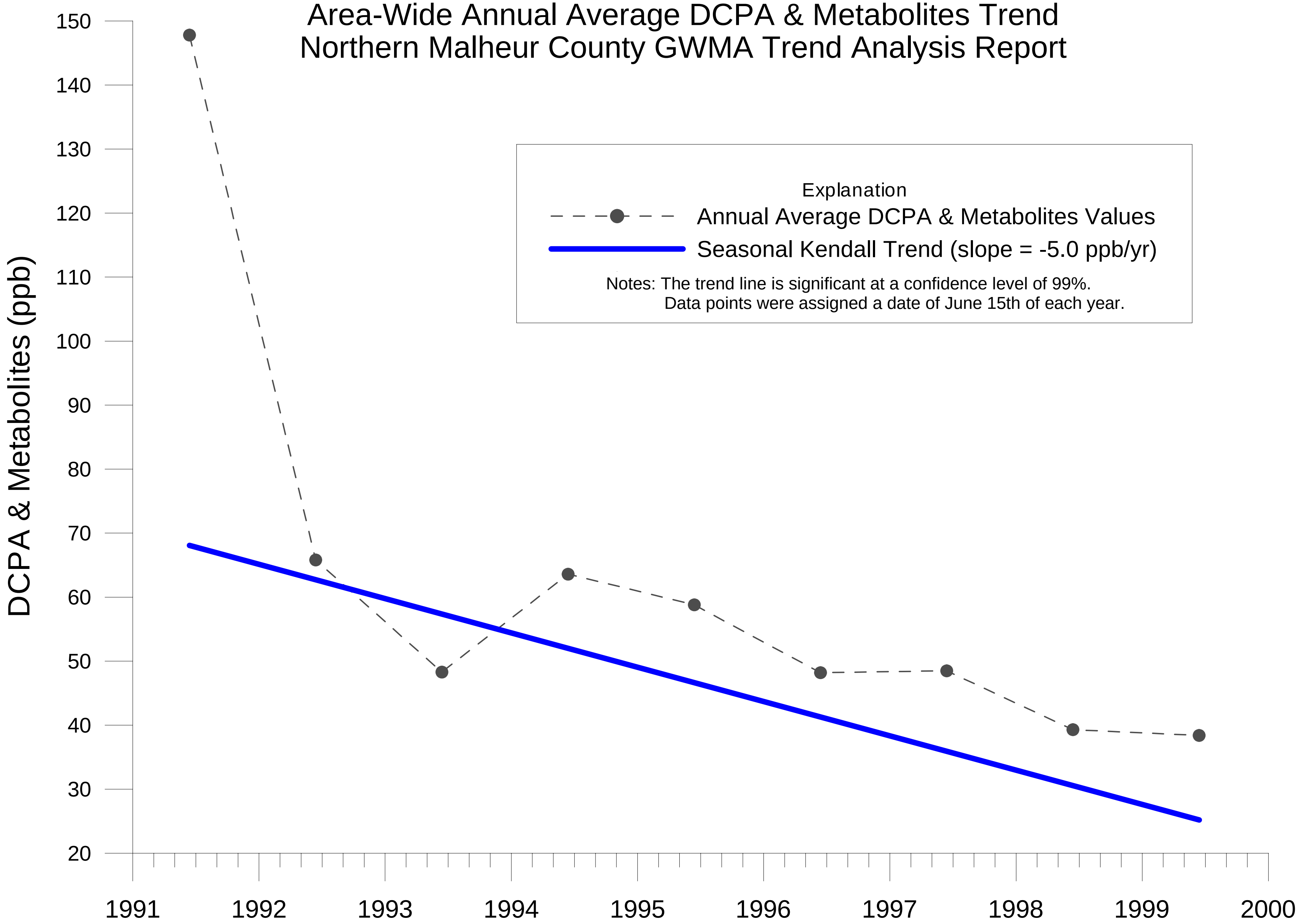
Figure 5-23
DCPA & Metabolites Trend vs. Well Depth
Northern Malheur County GWMA Trend Analysis Report



Notes:
(1) Two wells of unknown depth are assumed to be S&G AQ wells and are not plotted.
One has a slight increasing trend (1.4 ppb/yr) and the other has no significant trend.
(2) Wells with no significant trend are plotted with a 0.0 ppb/yr trend.

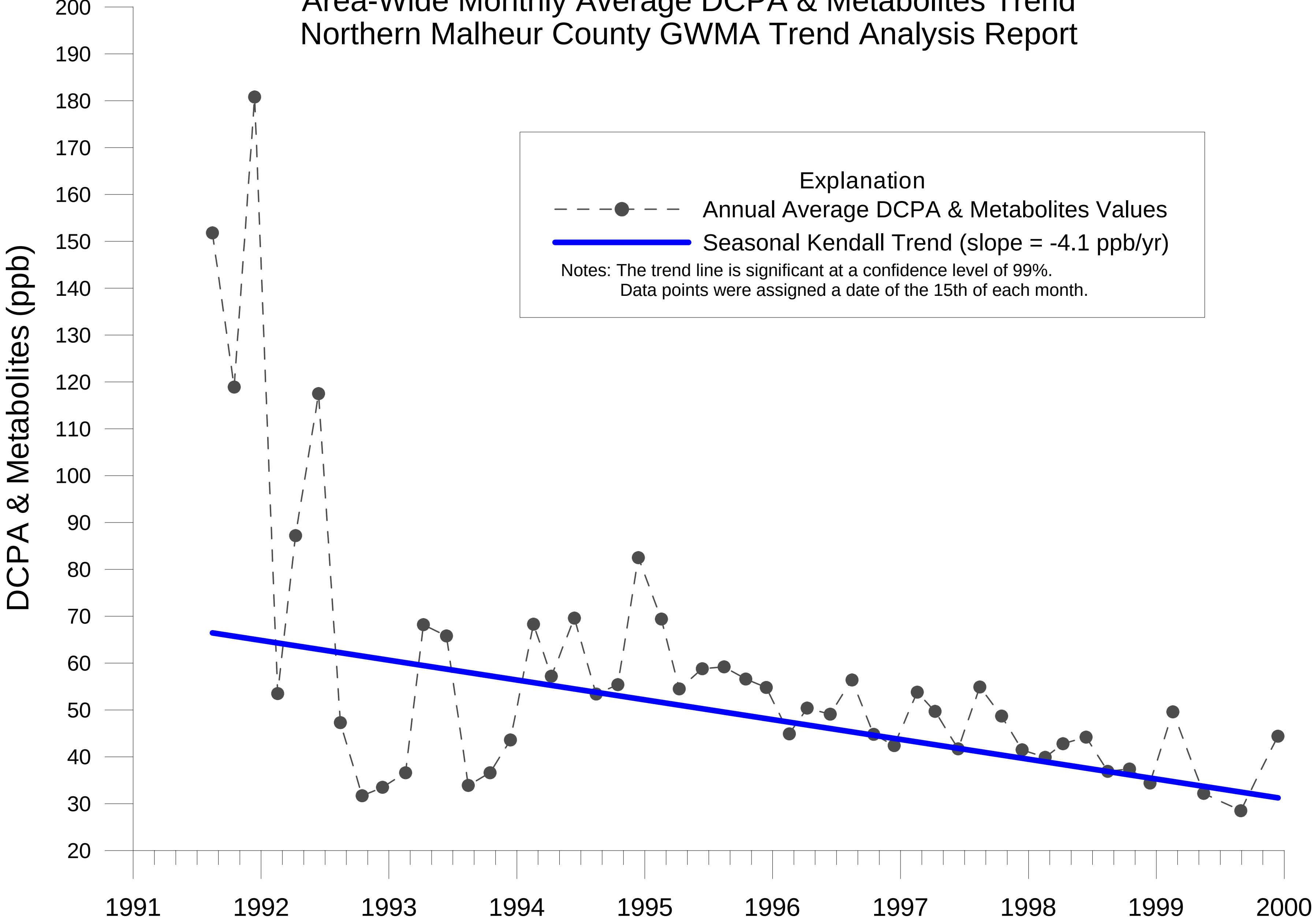
e: malheur 3rddraft dacdpth.grf

Figure 5-24
Area-Wide Annual Average DCPA & Metabolites Trend
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft anavgdac.grf

Figure 5-25
Area-Wide Monthly Average DCPA & Metabolites Trend
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft moavgdac.grf

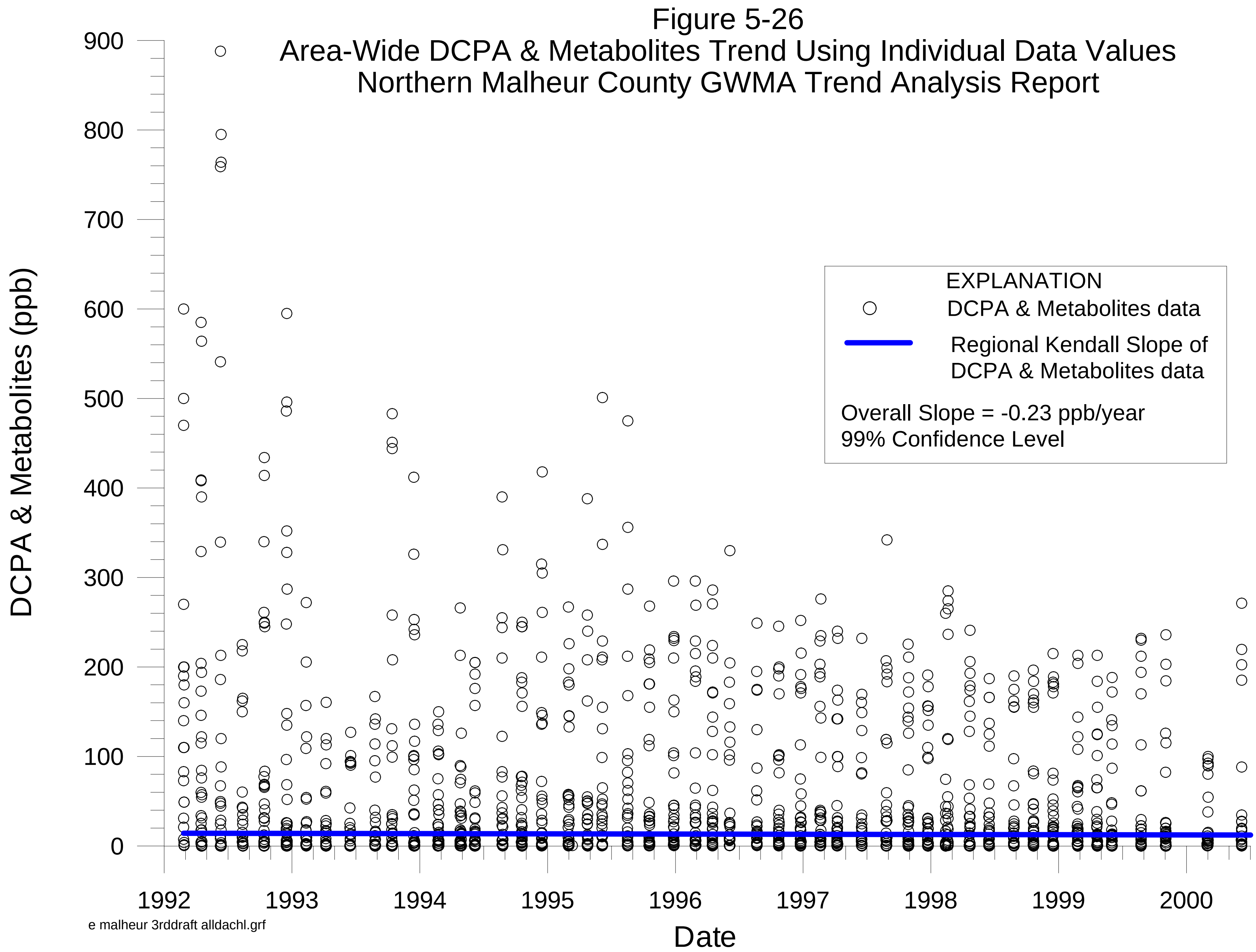
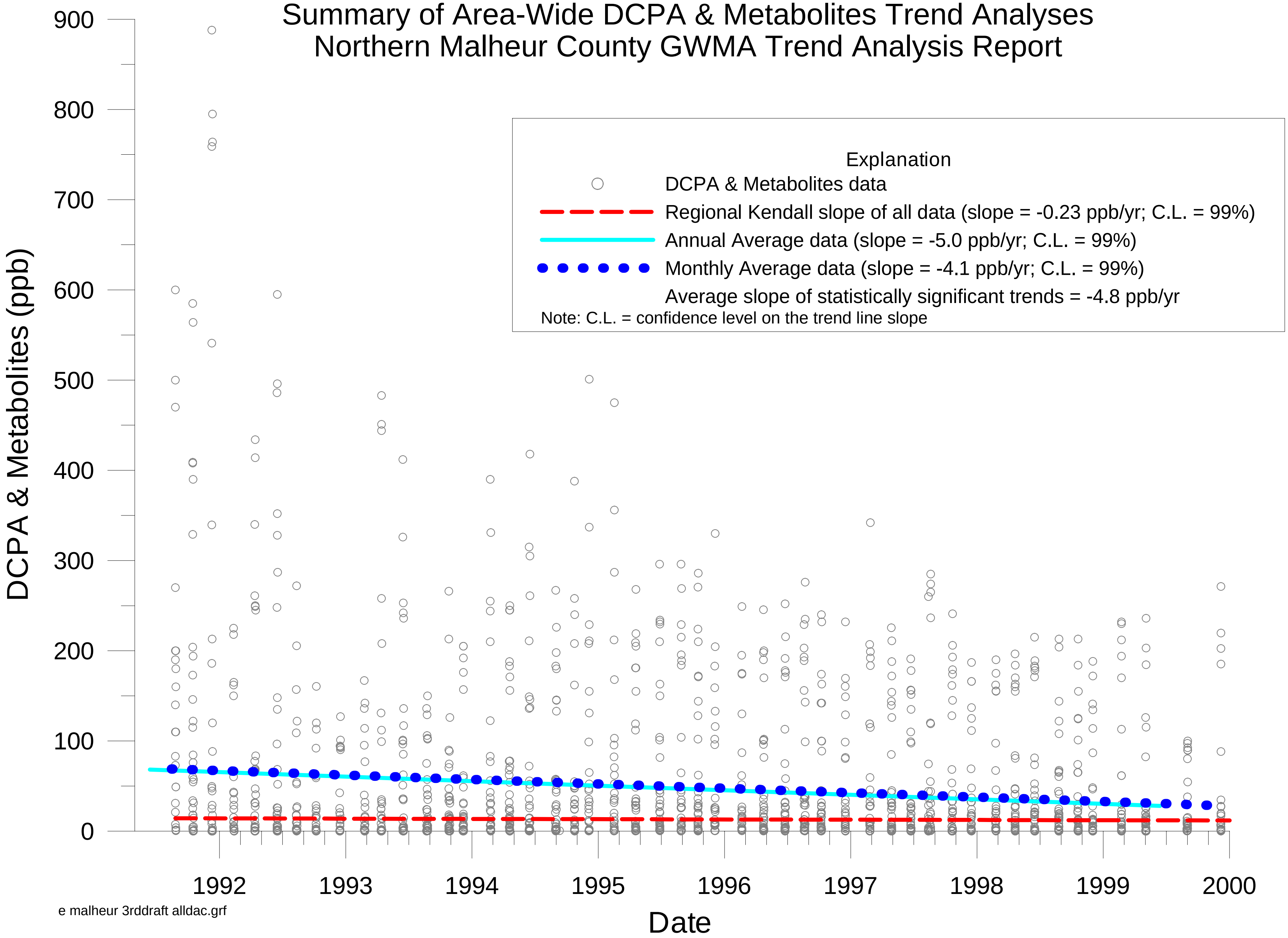


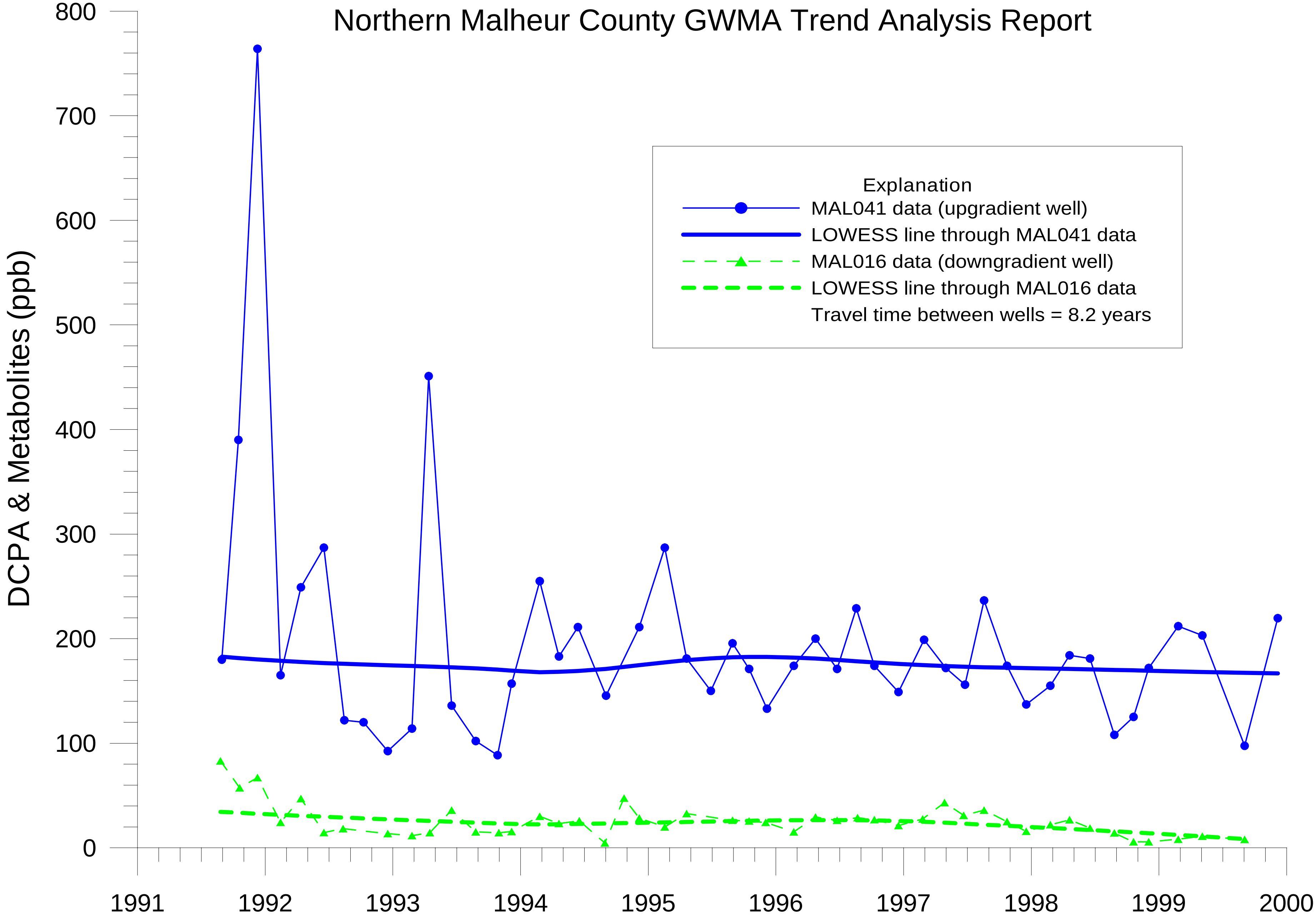
Figure 5-26
Area-Wide DCPA & Metabolites Trend Using Individual Data Values
Northern Malheur County GWMA Trend Analysis Report
DCPA & Metabolites (ppb)
900
800
700
600
500
400
300
200
100
0
1992
1993
1994
1995
1996
1997
1998
1999
2000
Date
EXPLANATION
DCPA & Metabolites data
Regional Kendall Slope of DCPA & Metabolites data
Overall Slope = -0.23 ppb/year
99% Confidence Level
e malheur 3rddraft alldachl.grf

Figure 5-27
Summary of Area-Wide DCPA & Metabolites Trend Analyses
Northern Malheur County GWMA Trend Analysis Report



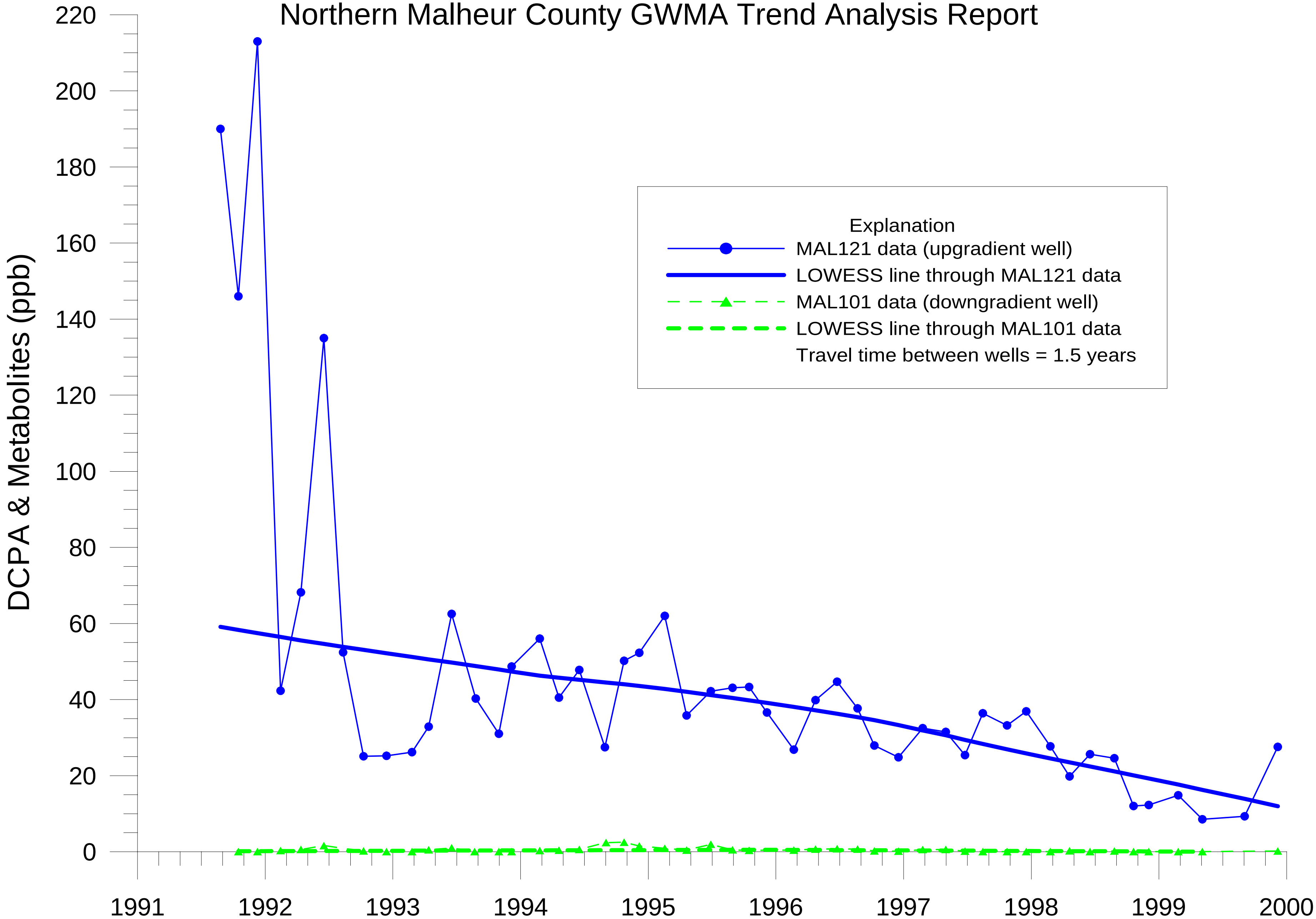
e malheur 3rddraft alldac.grf

Figure 5-28
Time Series Plot of Well Pair #1 DCPA & Metabolites Values
Northern Malheur County GWMA Trend Analysis Report



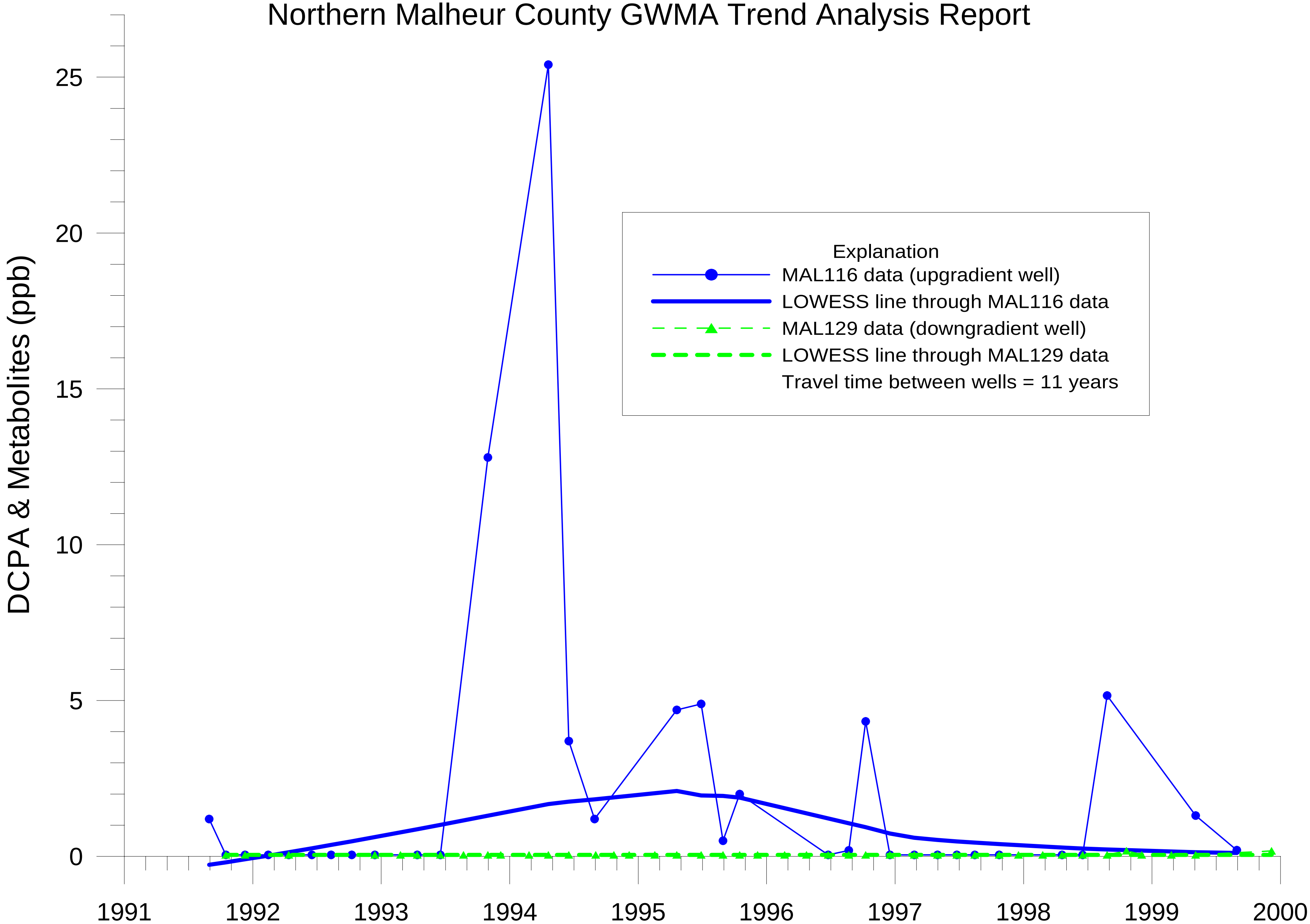
e: malheur 3rddraft pair1d$.grf

Figure 5-29
Time Series Plot of Well Pair #2 DCPA & Metabolites Values
Northern Malheur County GWMA Trend Analysis Report



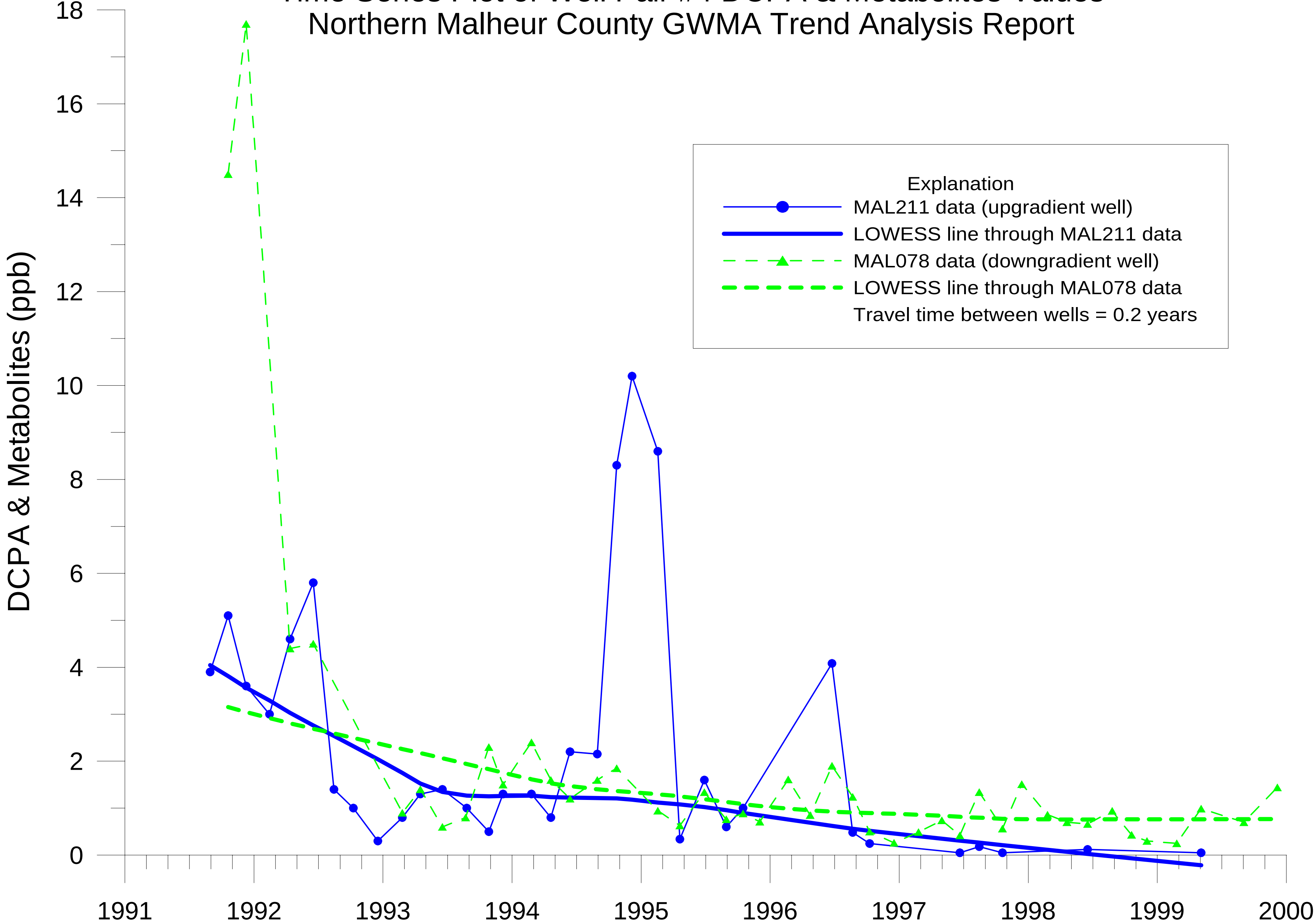
e: malheur 3rddraft pair2d$.grf

Figure 5-30
Time Series Plot of Well Pair #3 DCPA & Metabolites Values
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft pair3d$.grf

Figure 5-31
Time Series Plot of Well Pair #4 DCPA & Metabolites Values
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft pair4d$.grf

Appendix A
Comparison of Trends Using Various Methods and Datasets

INTRODUCTION
As indicated in Section 1.3 of the main report, multiple data sets were evaluated using several different techniques to determine what data should be included in the trend analysis and how the trend analysis should be conducted. Some background information and results of the evaluation are discussed below.

ACTION PLAN REQUIREMENTS
The Northern Malheur County Groundwater Management Area Action Plan requires DEQ to establish a regional groundwater monitoring network and perform periodic water quality assessments to evaluate the performance of the management plan in reducing the groundwater contamination resulting from agricultural activities. The Action Plan also states that in order to evaluate the effectiveness of BMP implementation, an analysis of data collected from indicator wells will be conducted five years after adoption of the plan (i.e., shortly after December 1996).

The Action Plan further states:

> "Nitrate trends over time will be determined by using linear regression of nitrate from the indicator wells from July 1, 1991, to the present at any future date. All data will be used as scatter plot data, with only dates included in the relationship for which complete data sets are available for the regression. That is to say there will be no missing data in the nitrate data used. The designated indicator wells will not be changed except through a formal amendment to the action plan."

COMPLICATIONS
Due to resource limitations, the formal trend analysis planned for five years after adoption of the plan was not completed in 1997 as intended. The trend analysis in this report (utilizing data from the 8½ years since adoption of the plan) was completed to evaluate the effectiveness of the Action Plan and complete the task specified in the Action Plan.

Since the issuance of the Action Plan, DEQ personnel have researched the various trend analysis techniques available. Based on this research it appears that linear regression is rarely the most appropriate technique to be used in trend analysis of groundwater quality data.

One item of debate over the past several years has been whether or not to include nitrate data generated by the electrode method in the trend analysis. Some of the trend analyses, discussed in Appendix C of this document, were performed both with and without these data. One objective of this study is to determine whether or not the electrode method data should be used in formal trend analyses. More information on this topic is provided below.

EVALUATION OF ELECTRODE METHOD NITRATE DATA
As indicated above, one item of debate over the past several years has been whether or not to include nitrate data generated by the electrode method in the trend analysis. Notes from a March 8, 1993 Citizen's Advisory Council meeting indicate that DEQ brought up the issue of potential problems using these data, proposed possible solutions, and requested recommendations on how to resolve the problem. The committee felt that the suggestion had no merit, no individual on the committee spoke in favor of excluding the electrode method data, and no motion was made in support of the suggestion.

DEQ continues to believe this is an important issue because ensuring consistency within a data set is critical when attempting to accurately detect small trends. Therefore, the use of the electrode method data is re-examined in this document and discussed below. In addition, several analyses were conducted both with and without the electrode method data for comparison. The differences in calculated trends resulting from the inclusion of the electrode method data are discussed in the following section.

DEQ has concluded that the electrode method nitrate data should not be used in this or future trend analyses. It should be noted that the conclusion to exclude the electrode method nitrate data is not a criticism of the people or organizations that collected, transported, or analyzed the samples. This conclusion is based on the following observations:

(1) *The electrode method nitrate data did not meet the project Quality Assurance Plan requirements for precision and accuracy.* Specific criteria were established which detail the precision and accuracy requirements for the sample results. The electrode method nitrate data did not meet these criteria.

(2) *The data were analyzed by two different methods*. Some data were obtained by using the nitrate electrode method (which quantifies nitrate) while other data were obtained by using the cadmium reduction colorimetric procedure (which quantifies nitrate + nitrite[1]). The cadmium reduction method has a lower method detection limit than the electrode method and therefore has better accuracy at nitrate levels less than 5 ppm. The use of the electrode method may have been the cause of these data not meeting the project Quality Assurance Plan requirements for precision and accuracy. As indicated in Section 2.2, consistent measurement techniques are required in order to detect or assess trends. The inherent variability of groundwater quality time series data requires that the collection and analysis of the trend analysis data be as consistent as possible (i.e., control what you can control).

(3) *The electrode method values are generally larger than the cadmium reduction method values obtained from split samples (i.e., samples collected at the same time and same place but analyzed by different methods*). Table A-1 is a comparison of the values from 101 split samples collected after 7/1/91 (the beginning of the trend analysis data set). As indicated in Table A-1, electrode method values were larger in 65% of the samples while cadmium reduction method values were larger in 21% of the samples (the values were equal in 14% of the samples). The electrode method values averaged 16.6 ppm while the cadmium reduction values averaged 14.2 ppm. Larger values at the beginning of the data set enhance the possibility of detecting a downward trend. If the larger values are not realistic, the downward trend may actually be less steep or non-existent.

(4) *The variability of the electrode method values is greater than the variability of the cadmium reduction method values*. At many well locations, the cadmium reduction method was being used before, during, and after the electrode method was used. It is understood that the inherent variability of groundwater quality results causes some fluctuation in a time series plot. At some well locations, the electrode method data and cadmium reduction method data appear to have similar variability (see Appendix B for all time versus concentration plots). However, Figures A-1 through A-4 are examples of where the variability of electrode method data is significantly greater than the variability of cadmium reduction data over the same time. Examination of Figures A-1 through A-4 graphically reveals the greater variability in electrode method data versus cadmium reduction data at four specific wells.

The variability can be statistically demonstrated by using the F-Test and Levene's Test. Figure A-5 illustrates the results of these tests which demonstrate a statistical difference in the variability of these data sets. The 95% confidence intervals calculated by the F-Test for the electrode method data are both wider and higher than the intervals for the cadmium reduction data indicating greater variance and higher values. The box plots calculated by Levene's Test also illustrate greater variance and higher values in the electrode method data set. The low P-values for both tests indicate the tests are statistically significant.

[1] Nitrite values in groundwater are typically small compared to nitrate values (much below 0.1 mg/l; Sawyer and McCarty, 1978). Therefore, nitrate + nitrite values for groundwater are essentially all nitrate**.**

The conclusion to exclude the electrode method data is consistent with the observations of Hirsch, et al., (1982) and Gilbert (1987) discussed in the last paragraph of Section 2.2 and the following conclusion drawn by Smith and McCann (2000): "Less accurate methods early in the record may produce not only high-biased data but also greater variance. The consequence of this is an artificial induction of a down-trend. Such data are therefore of little value in trend detection."

COMPARISON OF TRENDS ESTIMATED BY MULTIPLE METHODS

The following discussion contains a comparison of nitrate and DCPA & metabolites trends at the Northern Malheur County Groundwater Management Area network wells quantified using various statistical techniques and multiple datasets. The seven statistical techniques used in this evaluation are described in Table 1-1 of the main report and include: ordinary least squares (linear regression), Mann-Kendall, Spearman rho, seasonal least squares regression, sine / cosine seasonal least squares regression, Seasonal Kendall without correction for correlation, and the Seasonal Kendall with correction for correlation. The multiple datasets were constructed using nitrate results from either both analytical methods (i.e., electrode method and cadmium reduction method) or just the one used throughout the trend analysis timeframe (i.e., the cadmium reduction method). The use of various statistical techniques and multiple datasets illustrates their influence on the calculated trends. Some of the differences in estimated trends caused by using various statistical techniques and multiple data sets are discussed below. Conclusions are made to use a particular technique and data set that minimizes potentially misleading results.

It is worth noting that the Mann-Kendall and Spearman rho tests always produced the same trend line slope and almost always produced the same confidence level. Similarly, both versions of the Seasonal Kendall test always produced the same trend line slope, but the version correcting for serial correlation typically produced a lower confidence level.

Results of the trend analyses include two pieces of information for each test performed: a slope value and a confidence level. The slope value indicates the direction and magnitude of the trend while the confidence level indicates the statistical certainty of the result. Trends are either increasing (i.e., have a positive slope), decreasing (i.e., have a negative slope), or flat (i.e., have a slope of zero). The confidence level associated with these test results range from less than 80% to 99%. For this study, test results with confidence levels less than 80% are considered "statistically insignificant". This does not mean that the concentrations observed at these wells are insignificant or unworthy of attention. Instead, this means that the statistical test could not identify a linear trend with a high degree of assurance.

Nitrate Trends

Tables A-2 and A-3 summarize results from the nitrate trend analyses using data sets both with and without the electrode method data, respectively. These tables include some data set summary statistics, results of the correlation coefficient probability plot test for normality, results of the Kruskal-Wallis test for seasonality, results of the Durbin-Watson test for serial correlation, and the slope and associated confidence level for the seven monotonic techniques used in this evaluation.

As indicated previously, it has been concluded that the electrode method data should not be used in this or future trend analyses. However, a discussion of the trend analysis results that include the electrode method data is provided to illustrate the degree of differences that can occur when lower quality data are mixed with higher quality data.

Comparison of Results by Well

Trend Direction

An examination of Tables A-2 and A-3 reveals both similarities and differences between the results when seven different techniques are used to quantify trend. There is generally good agreement in trend direction (i.e., increasing, decreasing, or flat) at a given location between methods. For example, at approximately 75% of the locations, all seven estimates indicated the same trend direction. However, at about 25% of the locations, conflicting trend directions were estimated using the seven different techniques. Usually, these differences included both flat and either increasing or decreasing trends. Rarely did these differences include flat, decreasing, and increasing trends. The locations with variable trend directions typically exhibited small slopes (i.e., +0.10 ppm/yr to -0.10 ppm/yr) that were commonly statistically insignificant. However, statistically significant flat and decreasing trends were identified at some locations as the result of using multiple techniques.

Trend Magnitude

There are also differences in the trend magnitude (i.e., the slope of the trend line) when seven techniques are used. There is generally good agreement in the trend line slopes calculated for each location by the seven methods. At approximately 80% of the locations, the range is less than 0.5 ppm/yr. There are, however, five locations with a range exceeding 0.5 ppm/yr, although not all of the estimates are statistically significant.

The well exhibiting the largest range of trend line slopes is MAL078. Statistically significant trend estimates at well MAL078 range from 2.23 ppm/yr (calculated by the ordinary least squares method) to 0.53 ppm/yr (calculated by the Seasonal Kendall method). These results indicate a four-fold difference in trend slope. Because these data are not normally distributed and exhibit seasonality, the ordinary least squares method is not an appropriate tool to gauge trend, but the Seasonal Kendall method is appropriate. The ordinary least squares result suggests the nitrate trend at MAL078 is increasing four times faster than the Seasonal Kendall result. Two similar wells (i.e., exhibiting a wide range of statistically significant results) exhibit 1.5 to 2 fold differences in trend slope.

Comparison of Results by Method

Table A-4 consists of information taken from the bottom of Tables A-2 and A-3, and summarizes the differences in the direction and magnitude of nitrate trends calculated using the seven different techniques and two different data sets. As indicated in Table A-4, there are notable differences in the number of various types of trends identified at the 40 locations by different methods. There are also differences in the average trend slopes identified by different methods. These differences are greater when the electrode method data are included.

For example, the number of increasing trends ranges from 9 (calculated by the ordinary least squares method and using the electrode method data) to 17 (as calculated by the Spearman rho method without using the electrode method data). Similarly, the number of decreasing trends ranges from 9 (calculated by the Seasonal Kendall test with serial correlation correction including the electrode method data) to 17 (calculated using the seasonal least squares method including the electrode method data).

The average slope of significant trends is consistently downward when the electrode method data are used. The average slope of significant trends ranges from decreasing to increasing when the electrode method data are not used. There are also a larger number of decreasing trends estimated by the seven statistical methods when the electrode method data are included. These results are likely due to the fact that the electrode method data are in the early portion of the time series and are generally larger values than corresponding cadmium reduction method values.

Tables A-2 and A-3 indicate that most locations exhibited data that was not normally distributed and did not display seasonality. These data set characteristics suggest the Mann-Kendall method would be the most appropriate method for the majority of locations. However, the use of the Mann-Kendall method at locations where the data are not normally distributed but do display seasonality would be an inappropriate use of the method. In this study, the inappropriate use of the Mann-Kendall method, rather than the appropriate Seasonal Kendall method, typically over-estimated the trend line slope.

DCPA & Metabolites Trends

Table A-5 summarizes the results from the trend analyses of DCPA & Metabolites concentrations. This table also includes some data set summary statistics, results of the correlation coefficient probability plot test for normality, results of the Kruskal-Wallis test for seasonality, results of the Durbin-Watson test for serial correlation, and the slope and associated confidence level for the seven monotonic techniques used in this evaluation.

Comparison of Results by Well

Trend Direction

An examination of Table A-5 reveals both similarities and differences between the results when seven different techniques are used to quantify trend. There is generally good agreement in trend direction (i.e., increasing, decreasing, or flat) at a given location between methods. For example, at approximately 75% of the locations, all seven estimates indicated the same trend direction. However, at about 25% of the locations, conflicting trend directions were estimated using the 7 different techniques. At half of these locations, these differences included both flat and either increasing or decreasing trends. Less frequently did these differences include flat, decreasing, and increasing trends. The locations with variable trend directions typically exhibited small slopes (i.e., +2.0 ppb/yr to -2.0 ppb/yr) that were commonly statistically insignificant. However, statistically significant flat and decreasing trends were at one location (MAL129) while statistically significant increasing and decreasing trends were identified at another location (MAL125) as the result of using multiple techniques.

Trend Magnitude

There are also differences in the trend magnitude (i.e., the slope of the trend line) when seven techniques are used. There is generally good agreement in the trend line slopes calculated for each location by the seven methods. At approximately 90% of the locations, the range is less than 10 ppb/yr. There are, however, four locations with a range exceeding 10 ppb/yr, although not all of the estimates are statistically significant.

The well exhibiting the largest range of trend line slopes is MAL012. Statistically significant trend estimates at well MAL012 range from -9.45 ppb/yr (calculated by the Mann-Kendall method) to -27.34 ppb/yr (calculated by the seasonal least squares method). These results indicate a three-fold difference in trend slope. Because these data are not normally distributed and do not exhibit seasonality, the seasonal least squares method is not an appropriate tool to gauge trend, but the Mann-Kendall method is appropriate. The seasonal least squares result suggests the DCPA & Metabolites trend at MAL012 is decreasing three times faster than the Mann-Kendall result.

Perhaps the best example of differences caused by using differing techniques is well MAL125. Statistically significant trend estimates at this well range from +6.85 ppb/yr (calculated by the sine / cosine seasonal least squares method) to -7.65 ppb/yr (calculated by the ordinary least squares method). Because these data are not normally distributed and do not exhibit seasonality, neither of these methods are appropriate tools to gauge trend. The Mann-Kendall method, which is the most appropriate method for this dataset, estimates the trend to be statistically insignificant at -0.33 ppb/yr.

ROBUSTNESS OF SEASONAL KENDALL TEST

DEQ has previously recommended that the Seasonal Kendall method be used exclusively to quantify NMC GWMA trends. This method is a nonparametric method (so it does not require the data to be normally distributed) that accounts for seasonality and is robust to outliers and missing data. The primary disadvantage to using the Seasonal Kendall test exclusively is that the power of the test to detect a trend can be less if used on a data set that was normally distributed and non-seasonal.

As summarized in Table A-6, the loss of power to detect a trend was not a major problem for data sets in this study. For 1 of the 13 data sets that were normally distributed and non-seasonal (i.e., where ordinary least squares (OLS) would be an appropriate test), the Seasonal Kendall (SK) test lost enough power so that an otherwise statistically significant trend was not identified. For approximately half of the data sets, the trends identified by the OLS and SK methods had comparable statistical significance and roughly equivalent slopes. When the slopes differed between the OLS and SK trends, the SK trends were almost always steeper.

SUMMARY

Using different trend analysis techniques and data sets causes differences in the calculated trends. These include differences in both trend line direction and magnitude. The fact that using different data sets produces different trends supports the conclusion to exclude the electrode method data. The fact that using different trend analysis techniques produces different trends has two major implications:

1) it underscores the importance of using a technique that accommodates the complicating aspects of water quality data sets (e.g., missing data, non-normal distributions, and censored data), and
2) it suggests that the exclusive use of one technique (that is appropriate for all data set characteristics) would produce a more comparable set of results for comparisons made between wells and over time by eliminating variations in trend estimates produced by using multiple methods. The results would be more comparable both between wells for any given time (e.g., compare simultaneous trends in different areas), and at the same well at two different times (e.g., comparing a current trend to a past trend at a particular well).

CONCLUSIONS

Based on the information presented in this Appendix, the following conclusions have been made.

- the Seasonal Kendall test should be exclusively used to quantify trends in the Northern Malheur County Groundwater Management Area, and
- the electrode method data should not be used in trend analyses in the Northern Malheur County Groundwater Management Area.

These conclusions (to use a particular statistical technique and data set) involve an alternative approach to the trend analysis procedure currently specified in the Action Plan, but should minimize potentially misleading results from current and future trend analyses. A formal amendment to the Action Plan would be required to change the required trend analysis procedure.

Table A-1
Comparison of Nitrate Split Samples
Northern Malheur County GWMA Trend Analysis Report

Well ID	Date	Electrode Method Result (ppm nitrate)	Cadmium Reduction Method Result (ppm nitrate + nitrite)	Relative Percent Difference
MAL005	6/15/1993	7.3	5.6	26%
MAL012	2/23/1993	35.5	35	1%
MAL012	6/17/1993	25.8	27	5%
MAL016	2/24/1993	12.6	12.5	1%
MAL016	6/16/1993	15	13	14%
MAL030	12/10/1991	41.5	28	39%
MAL030	2/23/1993	25.9	29	11%
MAL030	6/16/1993	28.8	27	6%
MAL041	2/24/1993	16.8	17	1%
MAL041	6/17/1993	29.3	18	48%
MAL044	12/15/1992	25.4	20	24%
MAL044	12/17/1992	25.4	20	24%
MAL044	6/17/1993	21	20	5%
MAL047	6/16/1992	26.5	29	9%
MAL047	10/7/1992	41	39	5%
MAL047	2/25/1993	33	33	0%
MAL047	6/15/1993	39	37	5%
MAL062	2/25/1993	36.3	32	13%
MAL062	4/13/1993	17.5	31	56%
MAL062	6/15/1993	28	27	4%
MAL064	4/13/1993	4.6	4	14%
MAL064	6/15/1993	6.3	4.6	31%
MAL078	2/24/1993	2.6	2.6	0%
MAL078	6/17/1993	9.9	8.5	15%
MAL079	2/24/1993	9.6	10	4%
MAL079	6/17/1993	12.8	10	25%
MAL083	2/25/1993	35.4	37	4%
MAL083	6/17/1993	36	37	3%
MAL101	10/17/1991	1.4	1.5	7%
MAL101	10/25/1991	1.4	1.5	7%
MAL101	6/16/1992	1.4	1.4	0%
MAL101	6/16/1992	1.4	1.4	0%
MAL101	2/25/1993	3.8	3.9	3%
MAL101	4/13/1993	8.5	8.6	1%
MAL101	6/16/1993	15	13	14%
MAL105	12/10/1991	32	22	37%
MAL105	10/7/1992	16	15	6%
MAL105	12/15/1992	28.2	23	20%
MAL105	2/23/1993	21	20	5%
MAL105	6/15/1993	18.7	17	10%
MAL106	4/13/1993	16.5	17	3%
MAL106	6/15/1993	30	27	11%
MAL106	6/15/1993	28.3	27	5%
MAL108	10/25/1991	2.6	1.8	36%
MAL108	2/23/1993	<1	0.65	0%
MAL108	6/17/1993	3.5	2.1	50%
MAL108	6/17/1993	2.5	1.8	33%
MAL116	12/10/1991	3.3	2.5	28%
MAL116	12/12/1991	3.3	2.5	28%
MAL116	4/13/1993	8	6.3	24%
MAL116	6/16/1993	7.3	5.6	26%
MAL119	6/17/1993	12.5	12	4%

Well ID	Date	Electrode Method Result (ppm nitrate)	Cadmium Reduction Method Result (ppm nitrate + nitrite)	Relative Percent Difference
MAL121	10/16/1991	19.4	15	26%
MAL121	4/14/1993	15.5	13	18%
MAL121	6/16/1993	15	14	7%
MAL125	4/13/1993	7.7	6.6	15%
MAL125	6/16/1993	8.1	6.5	22%
MAL126	10/25/1991	19.4	15	26%
MAL126	6/16/1993	9.6	8.2	16%
MAL126	6/16/1993	11.1	8	32%
MAL129	2/25/1993	3.8	3.9	3%
MAL129	6/16/1993	5.1	3.7	32%
MAL136	2/25/1993	11.3	13	14%
MAL136	4/14/1993	14.7	14	5%
MAL136	6/16/1993	14.8	13	13%
MAL147	12/15/1992	<1	<0.02	0%
MAL147	12/16/1992	<1	<0.02	0%
MAL147	2/25/1993	<1	0.08	0%
MAL147	4/13/1993	<1	0.02	0%
MAL147	6/15/1993	<1	0.05	0%
MAL152	6/15/1993	16.5	15	10%
MAL164	4/13/1993	9.6	8.5	12%
MAL164	6/16/1993	6.8	5.2	27%
MAL172	2/25/1993	12.2	13	6%
MAL172	4/13/1993	12.6	13	3%
MAL172	6/15/1993	12.7	12	6%
MAL175	10/25/1991	15.5	15	3%
MAL175	4/13/1993	12	12	0%
MAL175	6/15/1993	16.5	16	3%
MAL180	4/13/1993	10	5	67%
MAL180	6/16/1993	5.2	4	26%
MAL189	2/25/1993	8.2	8.5	4%
MAL189	6/16/1993	10.8	8.4	25%
MAL211	6/18/1992	52	48	8%
MAL211	10/7/1992	50	41	20%
MAL211	10/7/1992	50	41	20%
MAL211	2/24/1993	47	48	2%
MAL211	6/17/1993	50.2	49	2%
MAL216	2/23/1993	<1	0.04	0%
MAL216	4/14/1993	<1	0.04	0%
MAL217	4/13/1993	12.6	12	5%
MAL217	6/15/1993	14.8	14	6%
OWY002	2/24/1993	4.6	4.7	2%
OWY002	6/16/1993	5.1	4	24%
OWY009	10/18/1991	1	0.26	117%
OWY101	2/24/1993	8.4	8.5	1%
OWY101	6/16/1993	10.4	8.9	16%
OWYDRN001	2/24/1993	4.2	4.2	0%
OWYDRN001	6/17/1993	1.9	1.4	30%
OWYDRN002	6/16/1993	4.6	2.7	52%
OWYDRN002	6/16/1993	3.9	2.7	36%
Average		***16.6***	***14.2***	***15%***
# of Larger Electrode Method Values			***66***	***65%***
# of Larger Cadmium Reduction Method Values			***21***	***21%***
# of Values Equal			***14***	***14%***

Note:

Relative Percent Difference is a measure of laboratory precision as is calculated as follows:

*[(Difference between 2 results) / (Average of 2 results)] * 100*

Table A-2
Summary of Individual Well Nitrate Trend Analyses Using Electrode Method Data + Cadmium Reduction Method Data
Northern Malheur County GWMA Trend Analysis

Sample Location	Data Set Statistics						Are Data Normally Distributed?	Are Data Seasonal?	Is There Serial Correlation?	Non-Seasonal Monotonic Trending Methods						Seasonal Monotonic Trending Methods							
										Ordinary Least Square (parametric)		Mann-Kendall (nonparametric)		Spearman Rho (nonparametric)		Seasonal Least Square (parametric)		Sine/Cosine Seasonal Least Square (parametric)		Seasonal Kendall w/o Correction (nonparametric)		Seasonal Kendall w/ Correction (nonparametric)	
	Min	Max	Mean	Median	n	% BDL				Slope	C.L.	Slope	C.L.	Slope	C.L.	Slope	C.L.	Slope	C.L.	Slope	C.L.	Slope	C.L.
MAL005	4.25	7.9	6.1	6.4	48	0%	No	No	No	0.25552	99%	0.23651	99%	0.23651	99%	0.26848	99%	0.25788	99%	0.22131	95%	0.22131	NS 80%
MAL012	9.39	36	25.7	26.0	50	0%	Yes	No	No	-0.82461	95%	-0.83908	95%	-0.83908	95%	-0.68175	95%	-0.84979	95%	-0.79574	99%	-0.79574	80%
MAL016	8.55	22	13.7	13.0	46	0%	No	No	No	-0.71576	99%	-0.74517	99%	-0.74517	99%	-0.71336	99%	-0.72209	99%	-0.75206	99%	-0.75206	95%
MAL030	23.5	37	28.5	28.0	49	0%	No	Yes	No	-0.00335	NS 80%	0.15781	80%	0.15781	80%	-0.00873	NS 80%	0.00814	NS 80%	0.04115	90%	0.04115	NS 80%
MAL035	19	37.2	29.5	30.0	50	0%	Yes	No	No	0.84101	99%	0.88872	99%	0.88872	99%	0.74061	99%	0.82997	99%	0.90662	99%	0.90662	95%
MAL041	16	29	18.4	18.0	50	0%	No	No	No	-0.07897	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.14487	NS 80%	-0.09082	NS 80%	0.00000	NS 80%	0.00000	NS 80%
MAL044	15	24	18.9	18.9	49	0%	Yes	No	No	-0.08836	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.10914	NS 80%	-0.10060	NS 80%	-0.03966	NS 80%	-0.03966	NS 80%
MAL047	20	48	35.0	35.0	50	0%	Yes	No	No	-0.62471	80%	-1.20462	95%	-1.20462	90%	-0.58631	80%	-0.65307	80%	-1.07283	80%	-1.07283	NS 80%
MAL062	22.1	54	37.9	39.0	49	0%	Yes	No	No	1.18748	95%	1.37126	95%	1.37126	99%	1.40442	99%	1.22764	95%	1.62492	99%	1.62492	NS 80%
MAL064	0.07	22	7.8	8.0	47	0%	No	Yes	No	-0.69980	99%	-0.49691	95%	-0.49691	95%	-0.73048	99%	-0.65806	99%	-0.50275	95%	-0.50275	80%
MAL078	0.58	43.6	8.8	6.5	43	0%	No	Yes	No	1.53629	99%	0.78912	90%	0.78912	90%	1.29512	95%	1.34521	95%	0.49239	80%	0.49239	80%
MAL079	3.51	18	9.5	9.6	44	0%	Yes	No	No	-0.57722	99%	-0.66742	99%	-0.66742	99%	-0.50109	95%	-0.55737	95%	-0.51495	90%	-0.51495	NS 80%
MAL083	8.9	64	25.1	21.0	41	0%	No	No	No	-3.03767	99%	-2.98339	99%	-2.98339	99%	-3.26218	99%	-3.10831	99%	-2.74812	99%	-2.74812	80%
MAL101	1.3	22	8.0	7.0	47	0%	No	No	No	0.04676	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.07299	NS 80%	-0.05075	NS 80%	0.20361	NS 80%	0.20361	NS 80%
MAL105	15.5	33	26.1	27.5	50	0%	No	Yes	No	1.43109	99%	1.47906	99%	1.47906	99%	1.35352	99%	1.40333	99%	1.34430	99%	1.34430	99%
MAL106	0.05	33.3	25.6	28.0	29	0%	No	No	No	-0.62727	NS 80%	0.24806	NS 80%	0.24806	NS 80%	0.02858	NS 80%	-0.60853	NS 80%	0.35277	80%	0.35277	NS 80%
MAL108	0.1	4	1.1	0.5	50	<1%	No	Yes	No	-0.11023	90%	-0.06405	95%	-0.06405	95%	-0.10292	95%	-0.09547	95%	-0.04690	99%	-0.04690	99%
MAL116	2.3	19	5.1	3.8	35	0%	No	No	No	-0.14327	NS 80%	0.05738	NS 80%	0.05738	NS 80%	-0.22584	NS 80%	-0.21950	NS 80%	0.05987	NS 80%	0.05987	NS 80%
MAL119	9.3	26	19.7	21.0	27	0%	No	Yes	No	2.20861	99%	2.16408	99%	2.16408	99%	2.05364	99%	2.04695	99%	1.95944	99%	1.95944	99%
MAL121	11	17.2	13.2	13.0	50	0%	No	No	No	-0.07581	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.13548	90%	-0.08567	NS 80%	0.00000	NS 80%	0.00000	NS 80%
MAL125	5.1	24	10.8	8.8	36	0%	No	No	No	-0.45398	80%	-0.34494	NS 80%	-0.34494	NS 80%	-0.36936	NS 80%	-0.43230	80%	-0.33455	NS 80%	-0.33455	NS 80%
MAL126	4.85	99	27.1	19.7	41	0%	No	Yes	No	1.01420	NS 80%	1.26198	90%	1.26198	90%	0.33193	NS 80%	0.69311	NS 80%	0.85931	80%	0.85931	80%
MAL129	2.6	8.1	4.4	4.2	45	0%	No	No	No	-0.14633	90%	-0.13012	80%	-0.13012	80%	-0.18713	95%	-0.15365	90%	-0.15162	90%	-0.15162	NS 80%
MAL136	7.78	16.5	10.2	9.8	49	0%	No	No	No	-0.73021	99%	-0.73036	99%	-0.73036	99%	-0.76806	99%	-0.74467	99%	-0.78294	99%	-0.78294	99%
MAL147	0.5	0.5	0.5	0.5	49	100%	No	No	Unknown	Software is unable to perform the analyses because all values are set to 0.5 ppm (one-half the highest detection limit)													
MAL152	4.5	36.5	13.0	11.6	30	0%	No	No	No	-1.19656	99%	-0.23043	NS 80%	-0.23043	NS 80%	-1.34053	95%	-1.19051	95%	-0.39873	NS 80%	-0.39873	NS 80%
MAL164	1.9	12.5	5.0	4.3	38	0%	No	No	No	-0.77785	99%	-0.71254	99%	-0.71254	99%	-0.80254	99%	-0.78956	99%	-0.78706	99%	-0.78706	99%
MAL172	2	18.3	9.9	10.0	47	0%	Yes	No	No	-0.54749	99%	-0.59410	99%	-0.59410	99%	-0.57804	95%	-0.54643	95%	-0.62249	99%	-0.62249	80%
MAL175	10	22	15.0	14.0	48	0%	No	No	No	0.27909	90%	0.31499	95%	0.31499	95%	0.23170	80%	0.24319	80%	0.26431	80%	0.26431	NS 80%
MAL180	2.2	7.5	4.0	3.8	44	0%	No	Yes	No	0.06376	NS 80%	0.08162	NS 80%	0.08162	NS 80%	0.06465	NS 80%	0.05290	NS 80%	0.09268	90%	0.09268	NS 80%
MAL189	7.4	18	8.9	8.7	40	0%	No	No	Inconclusive	-0.12177	NS 80%	0.11277	95%	0.11277	95%	-0.11653	NS 80%	-0.13142	NS 80%	0.12657	95%	0.12657	80%
MAL211	16.2	76	46.7	0.5	36	0%	No	No	No	-0.05079	NS 80%	0.10778	NS 80%	0.10778	NS 80%	-1.68117	80%	-0.23779	NS 80%	-0.50241	NS 80%	-0.50241	NS 80%
MAL216	0.5	0.5	0.5	0.5	46	100%	No	No	Unknown	Software is unable to perform the analyses because all values are set to 0.5 ppm (one-half the highest detection limit)													
MAL217	11	20	15.3	15.0	41	0%	Yes	No	No	0.84887	99%	0.81936	99%	0.81936	99%	0.87336	99%	0.87257	99%	0.96761	99%	0.96761	95%
MAL218	1.8	46.5	26.5	27.0	29	0%	Yes	No	No	-1.49305	80%	-2.35732	99%	-2.35732	95%	-1.76715	80%	-1.58110	80%	-2.51507	95%	-2.51507	90%
OWY002	3.1	8	4.7	4.7	48	0%	No	No	No	0.03105	NS 80%	0.06923	90%	0.06923	90%	0.02532	NS 80%	0.02787	NS 80%	0.06806	90%	0.06806	90%
OWY009	0.01	7.1	2.9	2.8	28	4%	Yes	No	No	0.36525	99%	0.38299	99%	0.38299	99%	0.37380	99%	0.35781	99%	0.32834	95%	0.32834	90%
OWY101	2.54	11.8	9.0	9.0	50	0%	No	No	No	-0.12391	90%	-0.00461	NS 80%	-0.00461	NS 80%	-0.13535	95%	-0.13569	95%	-0.03678	NS 80%	-0.03678	NS 80%
OWYDRN001	0.98	6.85	4.0	4.2	45	0%	No	Yes	Inconclusive	0.08202	NS 80%	0.10649	NS 80%	0.10649	NS 80%	0.13060	95%	0.09856	80%	0.13469	95%	0.13469	90%
OWYDRN002	1.4	9.3	4.4	5.0	45	0%	No	Yes	No	-0.19542	80%	-0.09127	NS 80%	-0.09127	NS 80%	-0.22276	99%	-0.17199	95%	-0.17393	90%	-0.17393	NS 80%
						# of Increasing Trends ==>				9		13		13		10		10		16		10	
						# of Decreasing Trends ==>				16		12		12		17		16		13		9	
						# of Flat Trends ==>				2		2		2		2		2		2		2	
						# of Insignificant Trends ==>				13		13		13		11		12		9		19	
				Average slope of significant trends at the 38 wells ==>						-0.13		-0.06		-0.06		-0.22		-0.15		-0.06		-0.14	
				Average slope of all trends at the 38 wells ==>						-0.09		-0.04		-0.04		-0.17		-0.12		-0.07		-0.07	

Notes:

Min = minimum, Max = maximum, n = number of samples, BDL = below detection limit, C.L. = confidence level

The test for normality was performed using the correlation coefficient probablity plot with a 95% confidence level.

The test for seasonality was performed using the Kruskal-Wallis test with a 90% confidence level.

The test for serial correlation was performed using the Durbin Watson test.

Slopes are in ppm per year. Positive slopes indicate increasing trends and negative slopes indicate decreasing trends.

Wells MAL147 and MAL216 are reported as being 100% BDL because some electrode method results had detection limits higher than reported values using the cadmium reduction method.

E:\Malheur\3rd Draft\[all trends.xls]Both Data Types

Table A-3
Summary of Individual Well Nitrate Trend Analyses Using Cadmium Reduction Method Data Only
Northern Malheur County GWMA Trend Analysis

Sample Location	Data Set Statistics: Min	Max	Mean	Median	n	% BDL	Are Data Normally Distributed?	Are Data Seasonal?	Is There Serial Correlation?	Non-Seasonal Monotonic Trending Methods: Ordinary Least Square (parametric) Slope	C.L.	Mann-Kendall (nonparametric) Slope	C.L.	Spearman Rho (nonparametric) Slope	C.L.	Seasonal Monotonic Trending Methods: Seasonal Least Square (parametric) Slope	C.L.	Sine/Cosine Seasonal Least Square (parametric) Slope	C.L.	Seasonal Kendall w/o Correction (nonparametric) Slope	C.L.	Seasonal Kendall w/ Correction (nonparametric) Slope	C.L.
MAL005	4.25	7.7	6.2	6.7	41	0%	No	No	No	0.37981	99%	0.34217	99%	0.34217	99%	0.42420	99%	0.39854	99%	0.38405	99%	0.38405	80%
MAL012	9.39	36	25.4	25.0	45	0%	Yes	No	No	-0.80711	95%	-0.88594	95%	-0.88594	90%	-0.66879	90%	-0.86245	95%	-0.89153	95%	-0.89153	NS 80%
MAL016	8.55	19	13.3	13.0	41	0%	No	No	No	-0.68797	99%	-0.76639	99%	-0.76639	99%	-0.71145	99%	-0.70380	99%	-0.75258	99%	-0.75258	95%
MAL030	26	31	28.3	28.0	44	0%	Yes	Yes	No	0.17152	95%	0.13989	90%	0.13989	90%	0.18878	99%	0.19548	99%	0.22432	95%	0.22432	80%
MAL035	19	35.7	29.6	30.0	44	0%	No	No	No	1.02370	99%	0.95603	99%	0.95603	99%	0.94379	99%	1.02186	99%	0.99662	99%	0.99662	95%
MAL041	16	21.6	17.9	18.0	44	0%	No	No	No	0.25096	99%	0.14047	95%	0.14047	95%	0.22244	99%	0.27321	99%	0.20069	95%	0.20069	90%
MAL044	15	22	18.5	18.6	44	0%	Yes	No	No	0.15253	80%	0.00000	NS 80%	0.00000	NS 80%	0.13836	NS 80%	0.14192	NS 80%	0.09411	NS 80%	0.09411	NS 80%
MAL047	21.8	48	34.7	35.0	46	0%	Yes	No	No	-0.53303	NS 80%	-1.06119	95%	-1.06119	80%	-0.41281	NS 80%	-0.54430	NS 80%	-0.99197	NS 80%	-0.99197	NS 80%
MAL062	22.1	54	39.0	40.0	43	0%	Yes	No	No	0.83029	80%	0.87452	NS 80%	0.87452	80%	1.06564	90%	0.84528	80%	1.33106	80%	1.33106	NS 80%
MAL064	0.07	22	7.4	7.8	44	0%	No	Yes	No	-0.52963	NS 80%	-0.22289	NS 80%	-0.22289	NS 80%	-0.48753	95%	-0.43273	90%	-0.29945	NS 80%	-0.29945	NS 80%
MAL078	0.58	43.6	8.9	6.5	43	0%	No	Yes	No	2.22947	95%	0.90299	95%	0.90299	95%	1.98013	99%	1.99707	99%	0.53321	80%	0.53321	80%
MAL079	3.51	18	9.3	9.5	40	0%	Yes	No	No	-0.55485	95%	-0.64464	95%	-0.64464	95%	-0.49615	80%	-0.55005	90%	-0.53512	80%	-0.53512	NS 80%
MAL083	8.9	47	24.4	21.2	38	0%	No	No	No	-3.48357	99%	-3.27845	99%	-3.27845	99%	-3.64710	99%	-3.51000	99%	-3.30018	99%	-3.30018	90%
MAL101	1.3	22	8.6	7.3	43	0%	No	Yes	No	-0.34370	80%	-0.59836	80%	-0.59836	NS 80%	-0.52223	80%	-0.43271	80%	-0.62160	80%	-0.62160	NS 80%
MAL105	15	33	26.1	28.0	47	0%	No	No	No	1.63385	99%	1.50875	99%	1.50875	99%	1.61313	99%	1.62759	99%	1.50573	99%	1.50573	99%
MAL106	0.05	31	25.2	28.0	26	0%	No	No	No	-0.51889	NS 80%	0.33092	NS 80%	0.33092	NS 80%	0.50310	NS 80%	-0.42819	NS 80%	0.63152	90%	0.63152	NS 80%
MAL108	0.1	4	1.0	0.5	46	0%	No	Yes	No	-0.12403	95%	-0.06447	95%	-0.06447	95%	-0.09916	95%	-0.09616	95%	-0.03993	95%	-0.03993	95%
MAL116	2.3	19	5.2	3.9	30	0%	No	No	No	-0.31246	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.60869	90%	-0.58480	95%	-0.25370	NS 80%	-0.25370	NS 80%
MAL119	9.3	26	19.7	21.0	27	0%	No	Yes	No	2.21437	99%	2.17406	99%	2.17406	99%	2.05977	99%	2.05124	99%	1.99454	99%	1.99454	99%
MAL121	12	15	13.0	13.0	45	0%	No	No	Inconclusive	0.01065	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.04755	NS 80%	0.00621	NS 80%	0.00000	NS 80%	0.00000	NS 80%
MAL125	5.1	24	10.9	8.8	32	0%	No	No	No	-0.61615	90%	-0.58369	90%	-0.58369	80%	-0.57608	80%	-0.62725	80%	-0.59918	NS 80%	-0.59918	NS 80%
MAL126	4.9	99	27.6	19.9	40	0%	No	Yes	No	0.61839	80%	1.18020	80%	1.18020	80%	-0.56803	NS 80%	-0.12319	NS 80%	0.55227	NS 80%	0.55227	NS 80%
MAL129	2.6	8.1	4.2	3.9	41	0%	No	No	No	0.01559	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.03782	NS 80%	-0.00078	NS 80%	-0.04599	NS 80%	-0.04599	NS 80%
MAL136	7.78	14	9.9	9.8	44	0%	No	No	No	-0.69045	99%	-0.72150	99%	-0.72150	99%	-0.73312	99%	-0.71418	99%	-0.75519	99%	-0.75519	99%
MAL147	0.01	0.36	0.03	0.01	44	64%	No	No	No	-0.00982	99%	0.00000	99%	0.00000	99%	-0.01157	95%	-0.01149	95%	0.00000	99%	0.00000	95%
MAL152	4.5	16	11.1	11.0	26	0%	Yes	No	No	0.26912	NS 80%	0.41714	80%	0.41714	80%	0.23207	NS 80%	0.26882	NS 80%	0.49379	NS 80%	0.49379	NS 80%
MAL164	1.9	8.45	4.1	3.6	32	0%	No	No	No	-0.53026	99%	-0.51385	99%	-0.51385	99%	-0.57239	99%	-0.53043	99%	-0.59055	99%	-0.59055	99%
MAL172	2	14	9.2	9.5	41	0%	Yes	No	No	-0.19166	NS 80%	-0.22263	NS 80%	-0.22263	80%	-0.16159	NS 80%	-0.13877	NS 80%	-0.20932	NS 80%	-0.20932	NS 80%
MAL175	10	22	14.9	14.0	44	0%	No	No	No	0.49112	99%	0.43984	99%	0.43984	99%	0.43654	95%	0.45058	99%	0.49440	95%	0.49440	80%
MAL180	2.3	5.6	4.0	4.0	40	0%	Yes	Yes	No	0.05393	NS 80%	0.04741	NS 80%	0.04741	NS 80%	0.04780	NS 80%	0.04062	NS 80%	0.07638	NS 80%	0.07638	NS 80%
MAL189	7.4	10	8.7	8.6	38	0%	Yes	No	No	0.13714	99%	0.12076	99%	0.12076	99%	0.15042	99%	0.13041	99%	0.10121	99%	0.10121	80%
MAL211	16.2	76	46	49	32	0%	No	No	No	0.23961	NS 80%	0.25357	NS 80%	0.25357	NS 80%	-1.55364	NS 80%	0.01389	NS 80%	-0.50275	NS 80%	-0.50275	NS 80%
MAL216	0.10	0.36	0.12	0.10	41	90%	No	No	No	-0.00974	95%	0.00000	95%	0.00000	95%	-0.01197	95%	-0.01127	99%	0.00000	95%	0.00000	90%
MAL217	12	20	15.4	15.0	40	0%	No	No	No	0.82938	99%	0.79854	99%	0.79854	99%	0.86170	99%	0.86217	99%	0.96761	99%	0.96761	95%
MAL218	1.8	46.5	26.5	27.0	29	0%	Yes	No	No	-1.49305	80%	-2.35732	99%	-2.35732	95%	-1.76715	80%	-1.58110	80%	-2.51507	95%	-2.51507	90%
OWY002	3.4	6	4.7	4.7	42	0%	Yes	No	No	0.10579	99%	0.10831	99%	0.10831	99%	0.10945	99%	0.10696	99%	0.10213	99%	0.10213	95%
OWY009	0.01	7.1	2.9	2.9	26	4%	Yes	No	No	0.46658	99%	0.47947	99%	0.47947	99%	0.48823	99%	0.47234	99%	0.39696	90%	0.39696	80%
OWY101	2.54	10	8.8	8.9	44	0%	No	No	No	-0.03555	NS 80%	0.03639	80%	0.03639	80%	-0.06798	NS 80%	-0.06684	NS 80%	0.03830	NS 80%	0.03830	NS 80%
OWYDRN001	0.98	6.85	3.9	4.2	39	0%	No	Yes	Inconclusive	0.20472	NS 80%	0.20710	80%	0.20710	80%	0.23686	99%	0.19245	95%	0.20484	99%	0.20484	99%
OWYDRN002	1.4	6.9	4.1	4.9	39	0%	No	Yes	Inconclusive	0.00058	NS 80%	0.04210	NS 80%	0.04210	NS 80%	-0.04722	NS 80%	0.01354	NS 80%	-0.02502	NS 80%	-0.02502	NS 80%

	Ordinary Least Square	Mann-Kendall	Spearman Rho	Seasonal Least Square	Sine/Cosine Seasonal Least Square	Seasonal Kendall w/o Correction	Seasonal Kendall w/ Correction
# of Increasing Trends ==>	15	16	17	14	14	15	13
# of Decreasing Trends ==>	12	11	11	14	14	10	6
# of Flat Trends ==>	0	2	2	0	0	1	2
# of Insignificant Trends ==>	13	11	10	12	12	14	19
Average slope of significant trends at the 38 wells ==>	0.08	-0.06	-0.02	-0.01	-0.01	-0.01	0.00
Average slope of all trends at the 38 wells ==>	0.02	-0.02	-0.02	-0.06	-0.03	-0.05	-0.05

Notes:

Min = minimum, Max = maximum, n = number of samples, BDL = below detection limit, C.L. = confidence level

The test for normality was performed using the correlation coefficient probablity plot with a 95% confidence level.

The test for seasonality was performed using the Kruskal-Wallis test with a 90% confidence level.

The test for serial correlation was performed using the Durbin Watson test.

Slopes are in ppm per year. Positive slopes indicate increasing trends and negative slopes indicate decreasing trends.

E:\Malheur\3rd Draft\[all trends.xls]Cd Reduction Method Trends

Table A-4
Comparison of Nitrate Trends Estimated Using Multiple Techniques and Data Sets
Northern Malheur County GWMA Trend Analysis Report

Type or Slope of Trends	With Electrode Method Data (Table A-1)		Without Electrode Method Data (Table A-2)	
	Minimum	Maximum	Minimum	Maximum
# of Increasing Trends (method)	9 (OLS)	16 (SK)	13 (SKC)	17 (SR)
# of Decreasing Trends (method)	9 (SKC)	17 (SLS)	6 (SKC)	14 (SLS & S/C)
# of Flat Trends (method)	All methods identified 2 flat trends due to inclusion of data with differing detection limits		0 (OLS, SLS, & S/C)	2 (M-K, SR, & SKC)
# of Statistically Insignificant Trends (method)	9 (SK)	19 (SKC)	10 (SR)	19 (SKC)
Average slope of significant trends at the 38 wells	-0.22 ppm/yr (SLS)	-0.06 ppm/yr (M-K, SR, & SK)	-0.06 ppm/yr (M-K)	+0.08 ppm/yr (OLS)
Average slope of all trends at the 38 wells	-0.17 ppm/yr (SLS)	-0.04 ppm/yr (M-K & SR)	-0.06 ppm/yr (SLS)	+0.02 ppm/yr (OLS)

OLS = ordinary least squares
SK = Seasonal Kendall
SKC = Seasonal Kendall with Correction for Serial Correlation
SLS = Seasonal Least Squares
M-K = Mann-Kendall
SR = Spearman rho
S/C = Sine / Cosine Seasonal Least Squares

Table A-5
Summary of Individual Well DCPA & Metabolites Trend Analyses
Northern Malheur County GWMA Trend Analysis Report

Sample Location	Data Set Statistics						Are Data Normally Distributed?	Are Data Seasonal?	Is There Serial Correlation?	Non-Seasonal Monotonic Trending Methods: Simple Least Square (parametric)		Mann-Kendall (nonparametric)		Spearman Rho (nonparametric)		Seasonal Monotonic Trending Methods: Seasonal Least Square (parametric)		Sine/Cosine Seasonal Least Square (parametric)		Seasonal Kendall w/o Correction (nonparametric)		Seasonal Kendall w/ Correction (nonparametric)	
	Min	Max	Mean	Median	n	% BDL				Slope	C.L.	Slope	C.L.	Slope	C.L.	Slope	C.L.	Slope	C.L.	Slope	C.L.	Slope	C.L.
MAL005	0.05	19.8	5.18	4.85	47	21%	No	No	No	1.78489	99%	1.63570	99%	1.63570	99%	1.80380	99%	1.76960	99%	1.76723	99%	1.76723	99%
MAL012	74.6	759	215.4	184.0	49	0%	No	No	No	-25.70024	99%	-9.45330	80%	-9.45330	90%	-27.33708	99%	-26.15640	99%	-14.54784	80%	-14.54784	NS 80%
MAL016	4.6	83	25.4	24.2	46	0%	No	No	No	-2.89909	99%	-1.98059	95%	-1.98059	95%	-2.67374	95%	-2.99946	99%	-1.82613	80%	-1.82613	NS 80%
MAL030	89.6	795	202.4	173.5	48	0%	No	No	No	-19.19238	99%	-12.98615	95%	-12.98615	95%	-18.28461	95%	-18.69662	99%	-13.03003	90%	-13.03003	NS 80%
MAL035	61.1	541	215.0	191.5	49	0%	No	No	No	-20.03959	99%	-17.17585	99%	-17.17585	99%	-19.00449	99%	-20.45458	99%	-15.53318	95%	-15.53318	80%
MAL041	88.5	764	195.2	174	48	0%	No	No	No	-13.00598	95%	-1.93296	NS 80%	-1.93296	NS 80%	-13.85381	95%	-13.44243	95%	0.24966	NS 80%	0.24966	NS 80%
MAL044	9.4	120	34	29.5	48	0%	No	No	No	-3.27206	95%	-0.58418	NS 80%	-0.58418	NS 80%	-3.05814	95%	-3.29098	95%	0.00000	NS 80%	0.00000	NS 80%
MAL047	37.9	888	257.2	211	49	0%	No	No	No	-32.95916	99%	-27.42779	99%	-27.42779	99%	-33.20612	99%	-33.19065	99%	-29.92664	99%	-29.92664	95%
MAL062	2.3	198	67	66.1	48	0%	No	No	No	7.08374	95%	7.60343	95%	7.60343	99%	8.72420	99%	7.01440	95%	8.27963	99%	8.27963	80%
MAL064	0.55	73	16.7	10.2	45	0%	No	No	No	-1.03360	NS 80%	-0.25525	NS 80%	-0.25525	NS 80%	-0.77044	NS 80%	-0.68628	NS 80%	-0.22667	NS 80%	-0.22667	NS 80%
MAL078	0.25	17.7	1.89	0.94	43	0%	No	No	No	-0.77559	99%	-0.20254	99%	-0.20254	99%	-0.89819	99%	-0.79567	99%	-0.22471	99%	-0.22471	95%
MAL079	1.23	88.4	10.02	4.27	42	0%	No	No	No	-5.18092	99%	-1.04947	99%	-1.04947	99%	-5.51095	99%	-5.25532	99%	-1.12778	99%	-1.12778	99%
MAL083	3.6	240	87.4	70.6	39	0%	No	No	No	-24.08973	99%	-16.54673	99%	-16.54673	99%	-23.58701	99%	-24.04765	99%	-15.78979	99%	-15.78979	95%
MAL101	0.05	2.5	0.48	0.27	45	36%	No	Yes	No	-0.05898	80%	-0.02730	90%	-0.02730	80%	-0.04081	NS 80%	0.06234	80%	0.00000	NS 80%	0.00000	NS 80%
MAL105	14.2	339.5	96.3	83.6	48	0%	No	No	No	-3.86854	NS 80%	-1.38974	NS 80%	-1.38974	NS 80%	-3.94902	NS 80%	-4.15573	NS 80%	0.03325	NS 80%	0.03325	NS 80%
MAL106	6.10	564	225	229	28	0%	No	No	No	-28.01045	99%	-24.07622	99%	-24.07622	99%	-23.71153	95%	-32.30056	99%	-23.54196	95%	-23.54196	95%
MAL108	0.05	49	4.6	1.9	49	2%	No	Yes	No	-1.88647	99%	-0.65963	99%	-0.65963	99%	-1.95886	99%	-1.86430	99%	-0.51325	99%	-0.51325	99%
MAL116	0.05	25.4	2.07	0.05	34	56%	No	No	No	-0.11151	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.11382	NS 80%	-0.17098	NS 80%	0.00000	NS 80%	0.00000	NS 80%
MAL119	3.7	200	101.3	102	25	0%	Yes	No	No	6.57837	80%	12.57611	90%	12.57611	80%	5.52929	NS 80%	4.45075	NS 80%	13.62134	90%	13.62134	90%
MAL121	8.55	213	46	36.4	49	0%	No	No	No	-10.47929	99%	-6.17787	99%	-6.17787	99%	-10.73215	99%	-10.53119	99%	-5.62485	99%	-5.62485	95%
MAL125	0.05	194	23.2	7.1	35	6%	No	No	No	-7.65605	95%	-0.33164	NS 80%	-0.33164	NS 80%	-7.26436	90%	6.84694	95%	0.42936	NS 80%	0.42936	NS 80%
MAL126	0.05	0.3	0.07	0.05	38	90%	No	Yes	No	-0.00133	NS 80%	0.00000	NS 80%	0.00000	NS 80%	0.00040	NS 80%	-0.00065	NS 80%	0.00000	NS 80%	0.00000	NS 80%
MAL129	0.05	0.18	0.06	0.05	43	95%	No	No	No	0.00433	95%	0.00000	95%	0.00000	95%	0.00496	95%	0.00454	95%	0.00000	95%	0.00000	95%
MAL136	6.1	186	40.4	28.4	49	0%	No	No	No	-8.67614	99%	-5.71611	99%	-5.71611	99%	-9.08307	99%	-8.71960	99%	-0.56080	99%	-0.56080	95%
MAL147	2.7	49.7	13.6	11.6	47	0%	No	No	No	-0.99481	95%	-0.32526	NS 80%	-0.32526	NS 80%	-1.09127	95%	-1.02266	95%	-0.42683	NS 80%	-0.42683	NS 80%
MAL152	3.2	261	59.6	43.2	30	0%	No	No	No	-18.17220	99%	-8.40882	99%	-8.40882	99%	-19.17636	99%	-18.53783	99%	-8.68824	95%	-8.68824	80%
MAL164	0.05	1.6	0.14	0.05	36	92%	No	No	No	-0.01279	NS 80%	0.00000	NS 80%	0.00000	NS 80%	0.01309	NS 80%	-0.01542	NS 80%	0.00000	NS 80%	0.00000	NS 80%
MAL172	0.05	13.1	2.5	1.3	47	2%	No	No	No	-0.37466	95%	-0.22060	95%	-0.22060	95%	-0.36105	90%	-0.37233	95%	-0.15341	NS 80%	-0.15341	NS 80%
MAL175	0.05	110	34.7	31	47	2%	No	No	No	-4.23184	99%	-2.67191	99%	-2.67191	99%	-3.89739	99%	-4.20289	99%	-2.40500	95%	-2.40500	90%
MAL180	0.05	7.8	1.2	0.53	43	37%	No	Yes	No	-0.02376	NS 80%	0.00000	NS 80%	0.00000	NS 80%	-0.05394	NS 80%	-0.05526	NS 80%	0.00000	NS 80%	0.00000	NS 80%
MAL189	5.1	59.6	22.1	19.7	39	0%	No	No	No	-1.69219	95%	-1.54849	90%	-1.54849	90%	-1.47148	80%	-1.56517	90%	-0.59712	NS 80%	-0.59712	NS 80%
MAL211	0.05	10.2	2.3	1.3	34	9%	No	No	No	-0.45723	95%	-0.30802	99%	-0.30802	99%	-0.42444	80%	-0.39177	80%	-0.46127	99%	-0.46127	90%
MAL216	1.0	11.1	4.25	2.7	43	0%	No	Yes	No	0.32822	80%	0.24098	95%	0.24098	95%	0.27304	90%	0.30777	95%	0.13019	80%	0.13019	NS 80%
MAL217	7.35	67.8	23.3	19.8	39	0%	No	No	No	-3.39469	99%	-2.43334	99%	-2.43334	99%	-3.17643	99%	-3.36592	99%	-2.43334	95%	-2.43334	NS 80%
MAL218	0.2	11.4	3.6	2.7	26	0%	No	No	No	-1.81513	99%	-1.44060	99%	-1.44060	99%	-2.00397	99%	-1.87427	99%	-1.50862	99%	-1.50862	90%
OWY002	0.05	1.89	0.72	0.7	49	4%	Yes	No	No	0.05119	95%	0.07259	99%	0.07259	95%	0.05117	95%	0.05165	95%	0.08297	99%	0.08297	80%
OWY009	0.05	0.79	0.16	0.05	27	56%	No	No	No	-0.00028	NS 80%	0.00000	NS 80%	0.00000	NS 80%	0.00262	NS 80%	-0.00275	NS 80%	0.00000	NS 80%	0.00000	NS 80%
OWY101	1.6	49	9.4	5.5	49	0%	No	No	No	-2.39863	99%	-0.99529	99%	-0.99529	99%	-2.50433	99%	-2.40726	99%	-1.00077	99%	-1.00077	95%
OWYDRN001	0.5	23.5	5.9	4.3	46	0%	No	Yes	No	0.15736	NS 80%	0.30428	NS 80%	0.30428	80%	0.26321	NS 80%	0.19972	NS 80%	0.21136	NS 80%	0.21136	NS 80%
OWYDRN002	0.6	20.2	3.6	2.7	46	0%	No	Yes	No	-0.58774	99%	-0.27255	90%	-0.27255	90%	-0.57963	99%	-0.56847	99%	-0.13260	NS 80%	-0.13260	NS 80%

	Simple Least Square	Mann-Kendall	Spearman Rho	Seasonal Least Square	Sine/Cosine Seasonal Least Square	Seasonal Kendall w/o Correction	Seasonal Kendall w/ Correction
# of Increasing Trends ==>	6	5	6	5	7	4	4
# of Decreasing Trends ==>	26	22	22	25	24	19	14
# of Flat Trends ==>	0	1	1	0	0	1	1
# of Insignificant Trends ==>	8	12	11	10	9	16	21
Average slope of significant trends at the 38 wells ==>	-7.15	-4.42	-4.42	-7.70	-7.31	-4.79	-4.38
Average slope of all trends at the 38 wells ==>	-5.96	-3.27	-3.27	-5.86	-5.79	-3.04	-3.04

Notes:

Min = minimum, Max = maximum, n = number of samples, BDL = below detection limit, C.L. = confidence level

The test for normality was performed using the correlation coefficient probablity plot with a 95% confidence level.

The test for seasonality was performed using the Kruskal-Wallis test with a 90% confidence level.

The test for serial correlation was performed using the Durbin Watson test.

Slopes are in ppm per year. Increasing trends are statistically significant and have a positive slope.

Decreasing trends are statistically significant and have a negative slope.

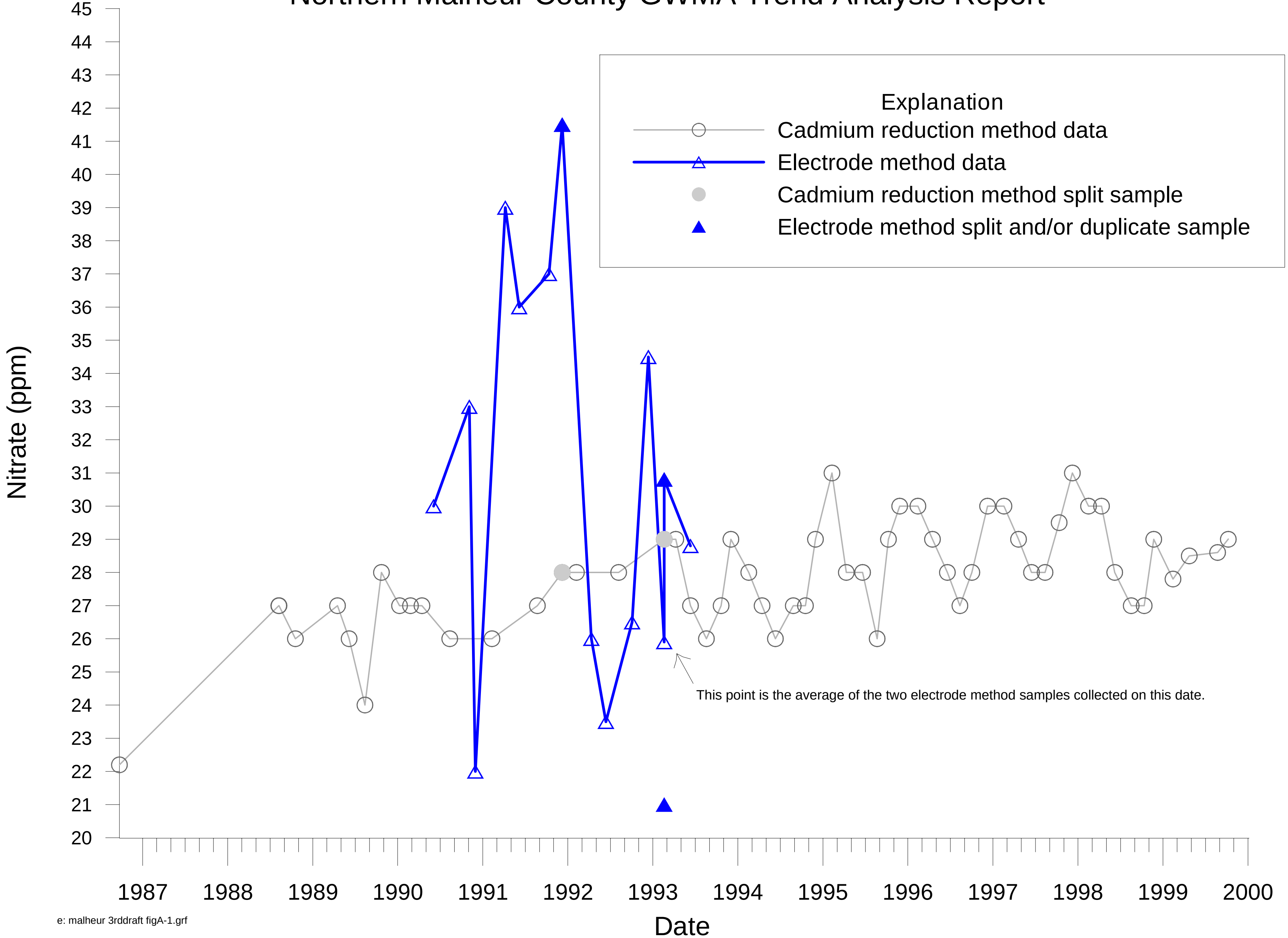
Flat trends are statistically significant and have a slope of zero.

Insignificant trends are statistically insignificant, regardless of slope.

Table A-6
Comparison of Some Ordinary Least Squares and Seasonal Kendall Trends
Northern Malheur County GWMA Trend Analysis Report

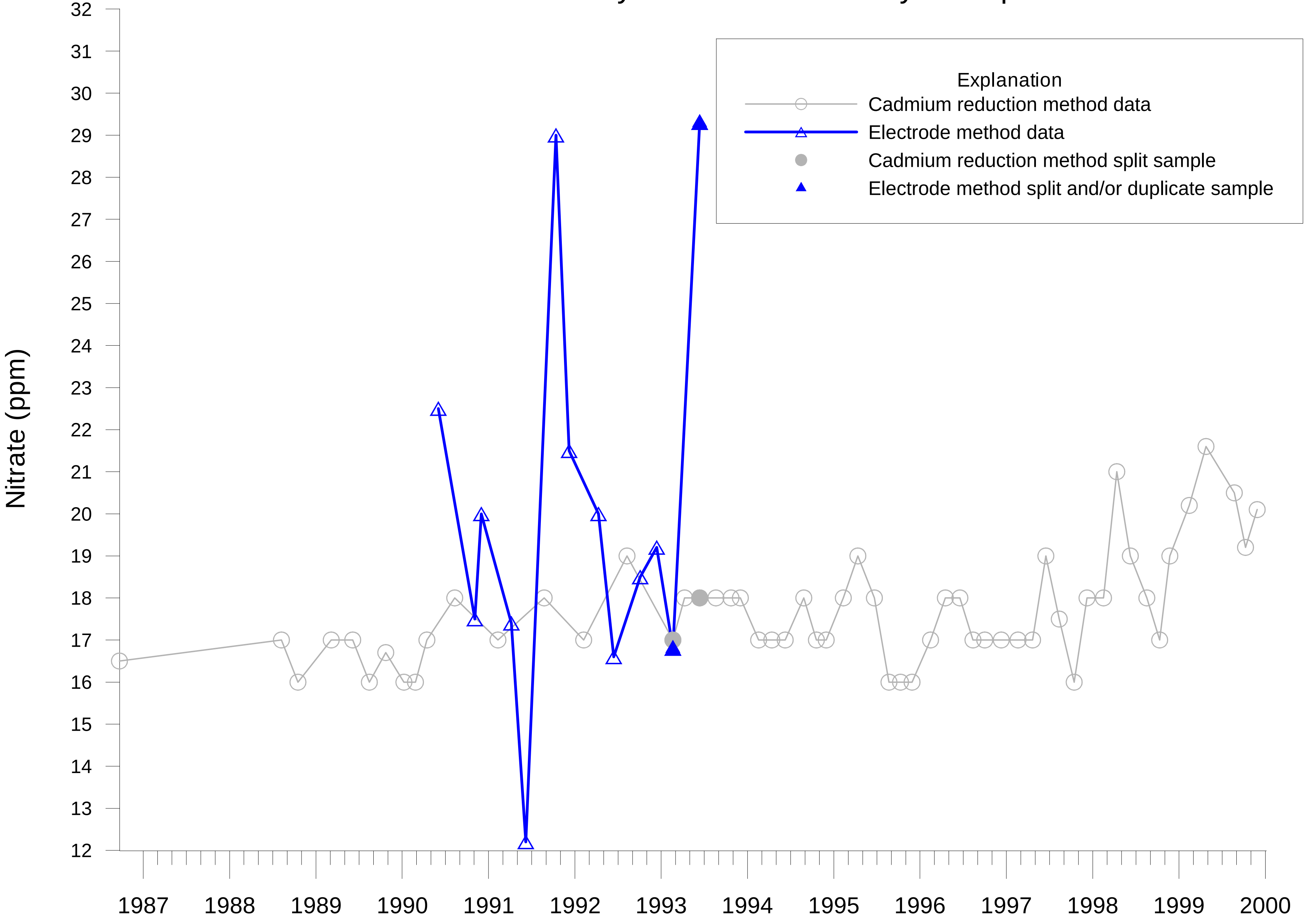
Well	Data Set	Ordinary Least Squares Trend		Seasonal Kendall Trend		Loss of Statistical Significance?	Slope Comparison
		Slope	C.L.	Slope	C.L.		
MAL012	Nitrate	-0.81 ppm/yr	95%	-0.89 ppm/yr	95%	No	Roughly equivalent
MAL044	Nitrate	0.15 ppm/yr	80%	0.09 ppm/yr	NS 80%	Yes	OLS is steeper
MAL047	Nitrate	-0.53 ppm/yr	NS 80%	-1.00 ppm/yr	NS 80%	No	S-K is steeper
MAL062	Nitrate	0.83 ppm/yr	80%	1.33 ppm/yr	80%	No	S-K is steeper
MAL079	Nitrate	-0.55 ppm/yr	95%	-0.54 ppm/yr	80%	No	Roughly equivalent
MAL152	Nitrate	0.27 ppm/yr	NS 80%	0.49 ppm/yr	NS 80%	No	S-K is steeper
MAL172	Nitrate	-0.19 ppm/yr	NS 80%	-0.21 ppm/yr	NS 80%	No	Roughly equivalent
MAL189	Nitrate	0.14 ppm/yr	99%	0.10 ppm/yr	99%	No	Roughly equivalent
MAL218	Nitrate	-1.50 ppm/yr	80%	-2.51 ppm/yr	95%	No	S-K is steeper
OWY002	Nitrate	0.11 ppm/yr	99%	0.10 ppm/yr	99%	No	Roughly equivalent
OWY009	Nitrate	0.47 ppm/yr	99%	0.40 ppm/yr	90%	No	Roughly equivalent
MAL119	DCPA & Metabolites	6.58 ppb/yr	80%	13.62 ppb/yr	90%	No	S-K is steeper
OWY002	DCPA & Metabolites	0.05 ppb/yr	95%	0.08 ppb/yr	99%	No	Roughly equivalent

Figure A-1
Variability of Electrode Method data and Cadmium Reduction Method data at Well MAL030
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft figA-1.grf

Figure A-2
Variability of Electrode Method Data and Cadmium Reduction Method Data at Well MAL041
Northern Malheur County GWMA Trend Analysis Report



e: malheur 3rddraft figA-2.grf

Figure A-3
Variability of Electrode Method Data and Cadmium Reduction Method Data at Well MAL044
Northern Malheur County GWMA Trend Analysis Report

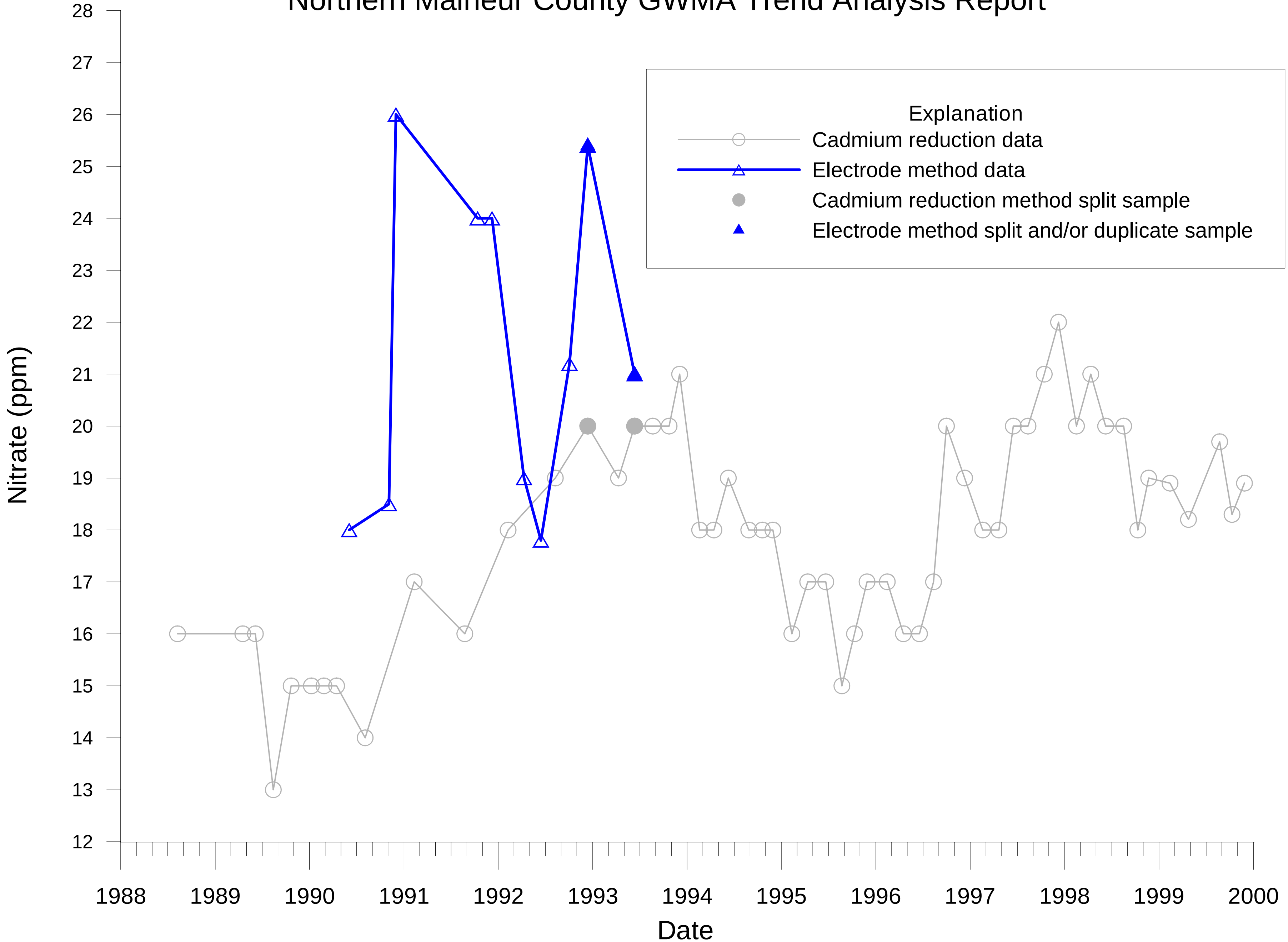
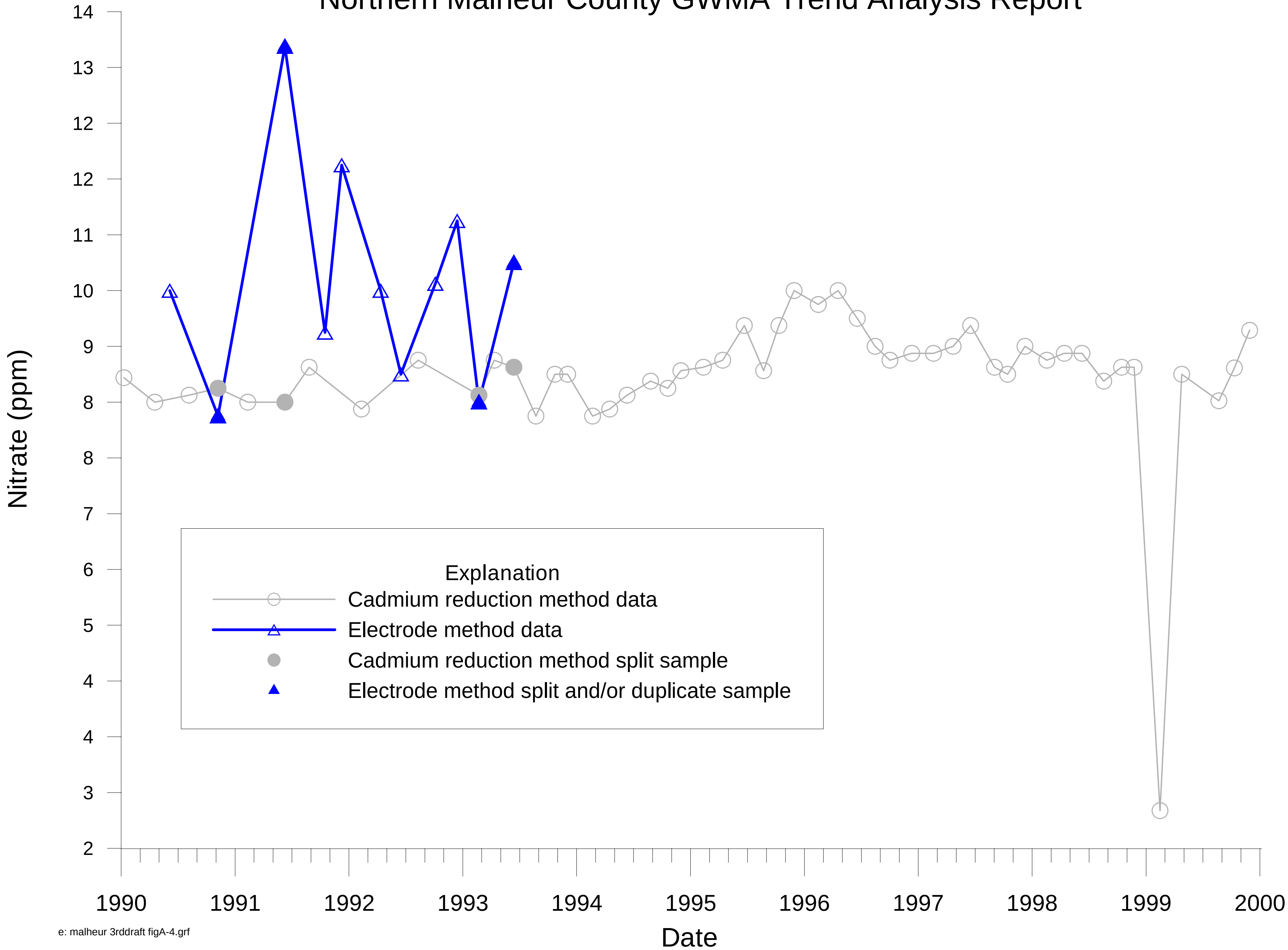
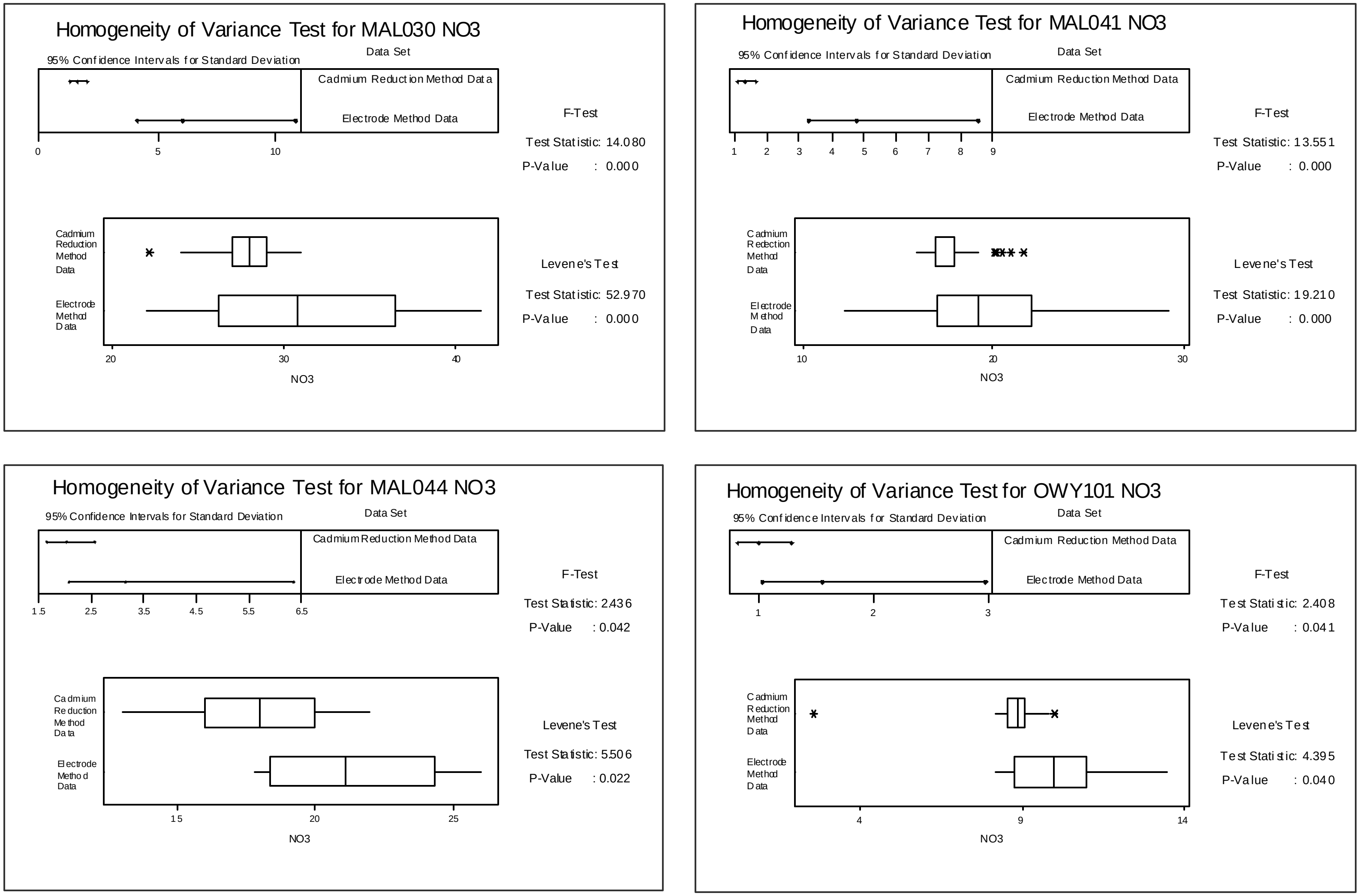


Figure A-4
Variability of Electrode Method Data and Cadmium Reduction Method Data at Well OWY101
Northern Malheur County GWMA Trend Analysis Report

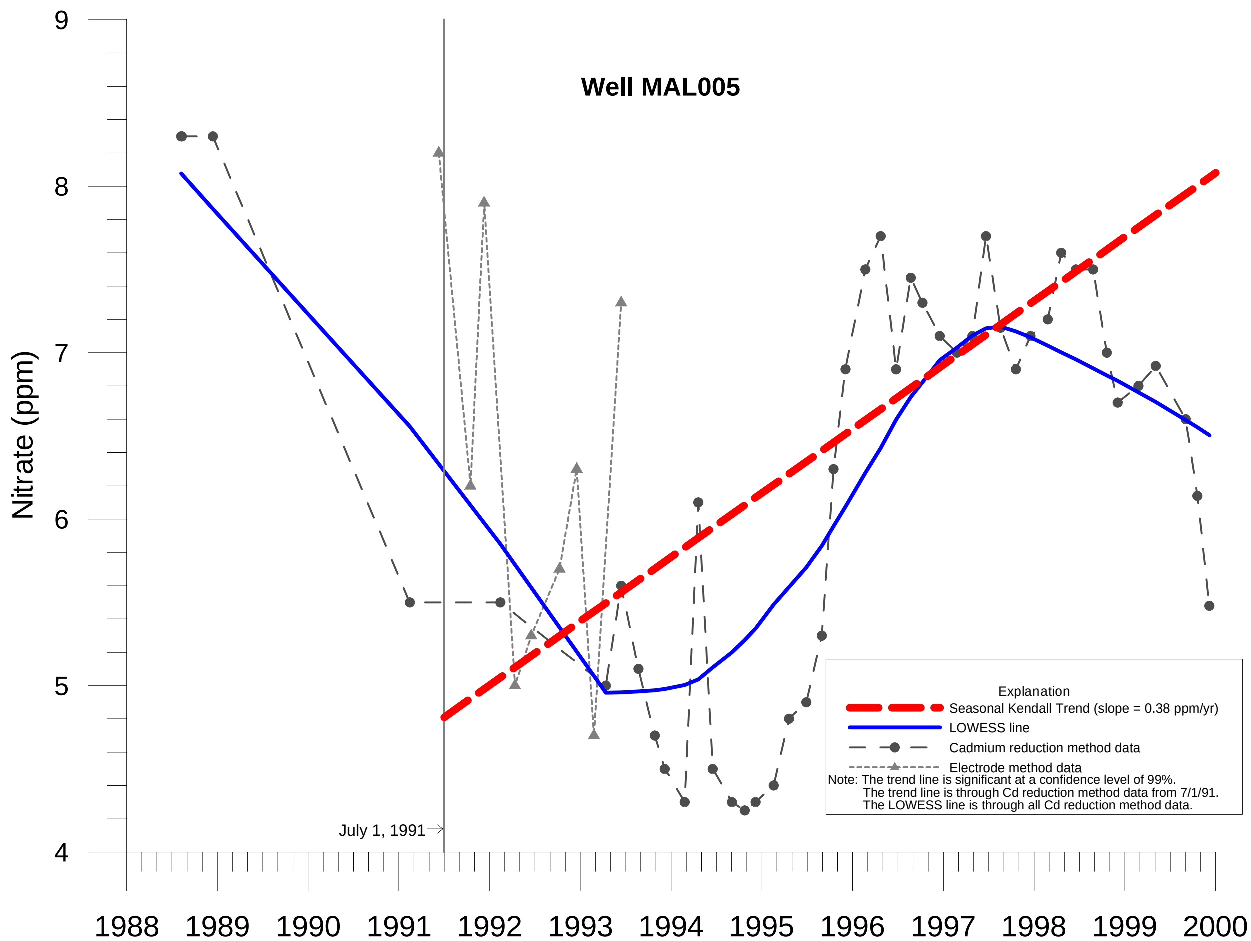


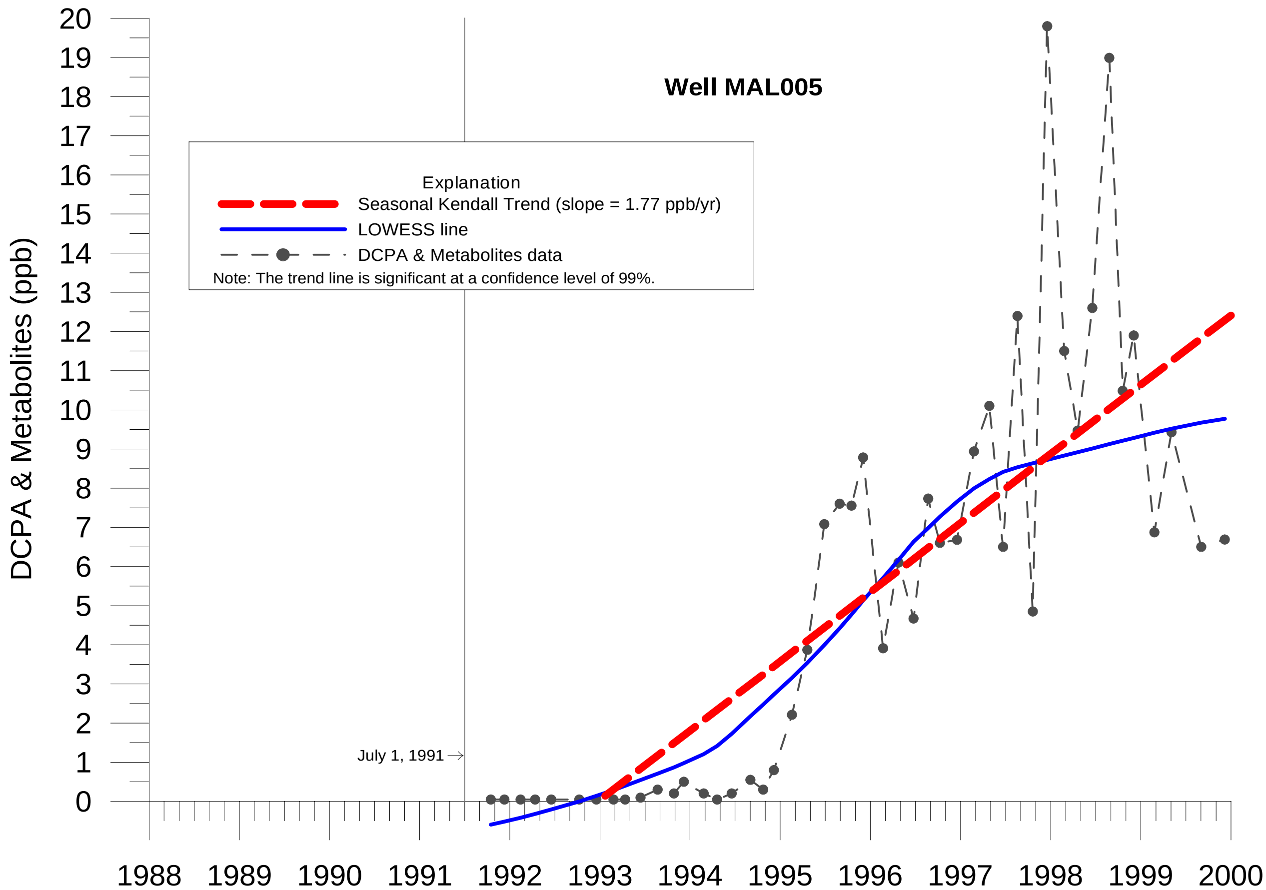
e: malheur 3rddraft figA-4.grf

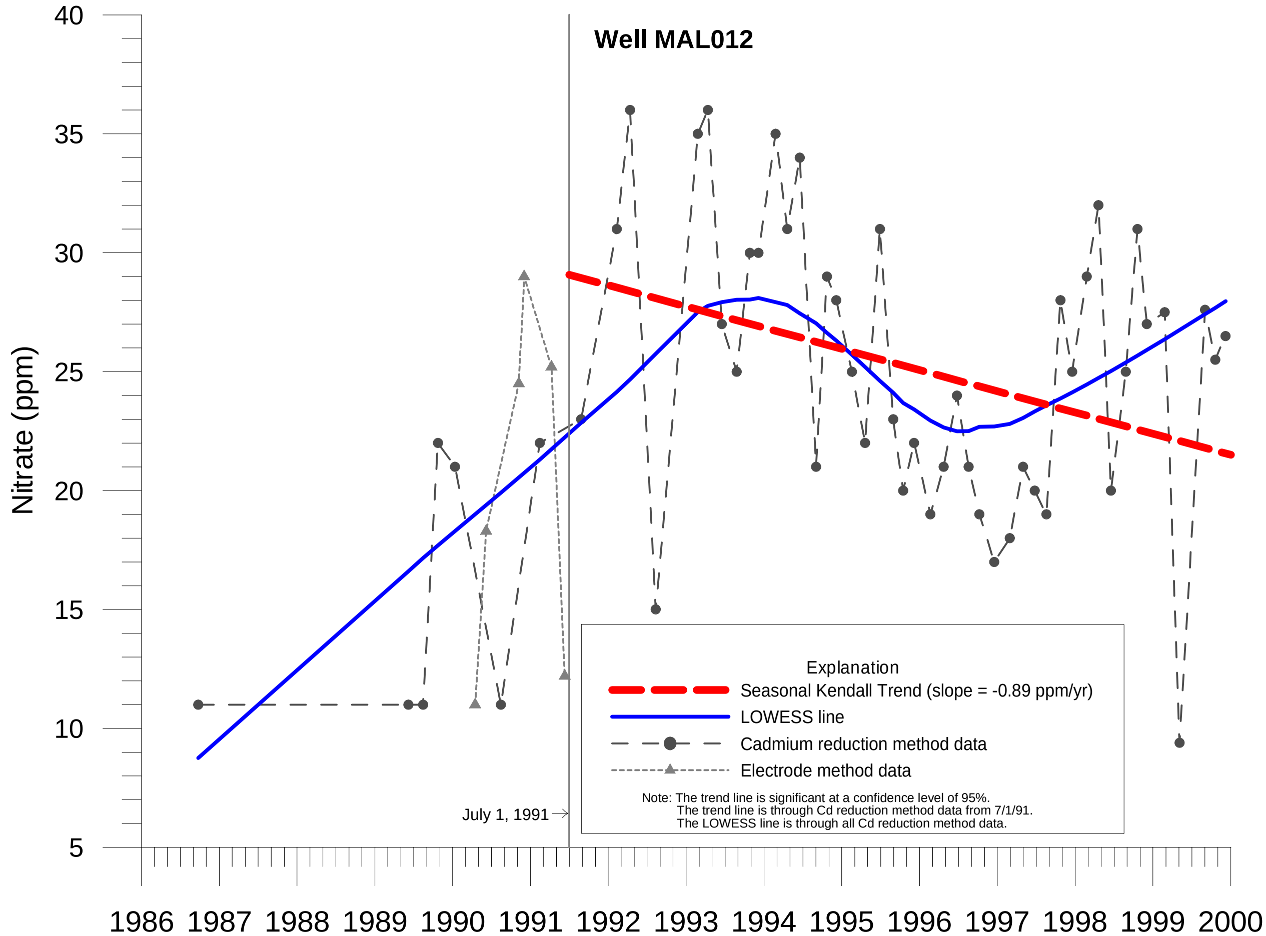
Figure A-5
Split Sample Variance Comparison
Northern Malheur County GWMA Trend Analysis Report

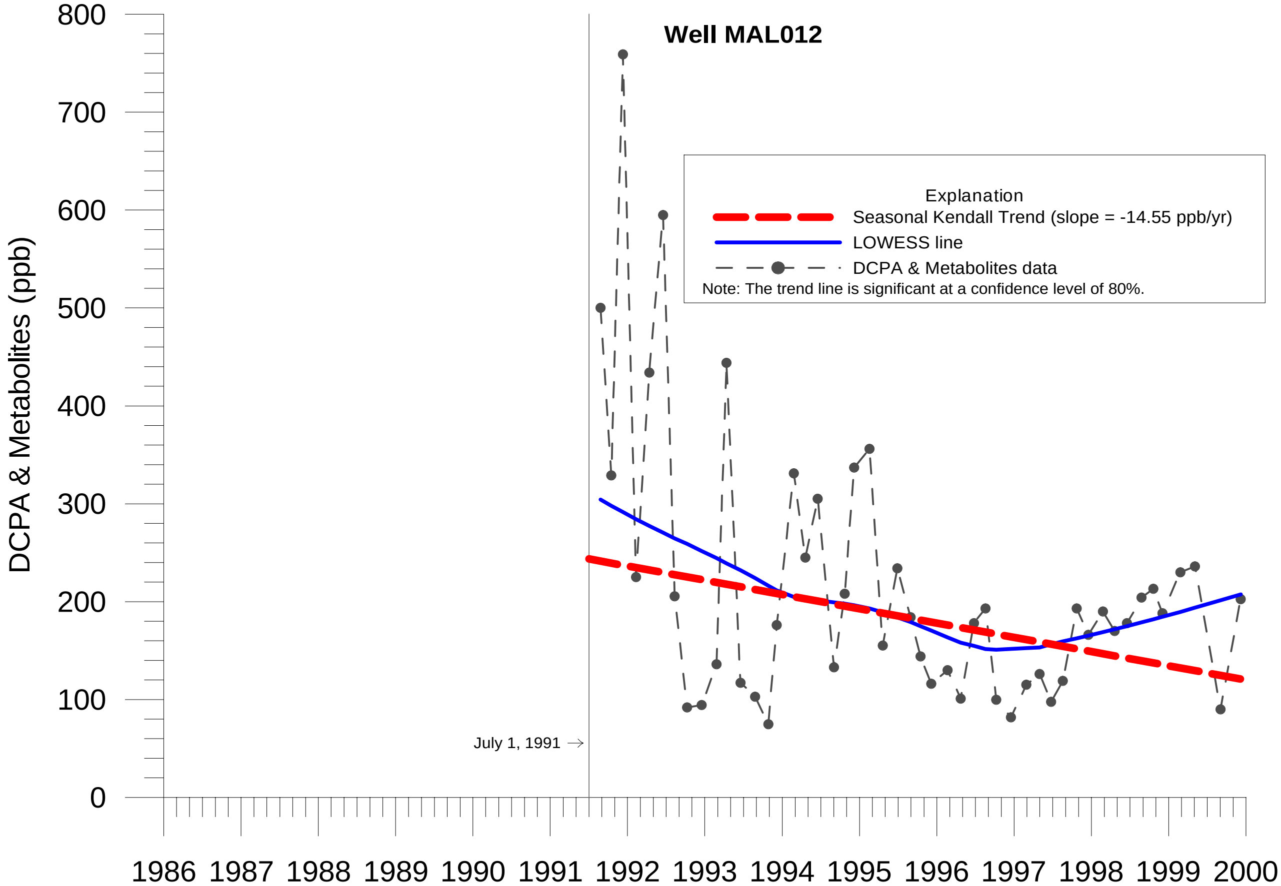


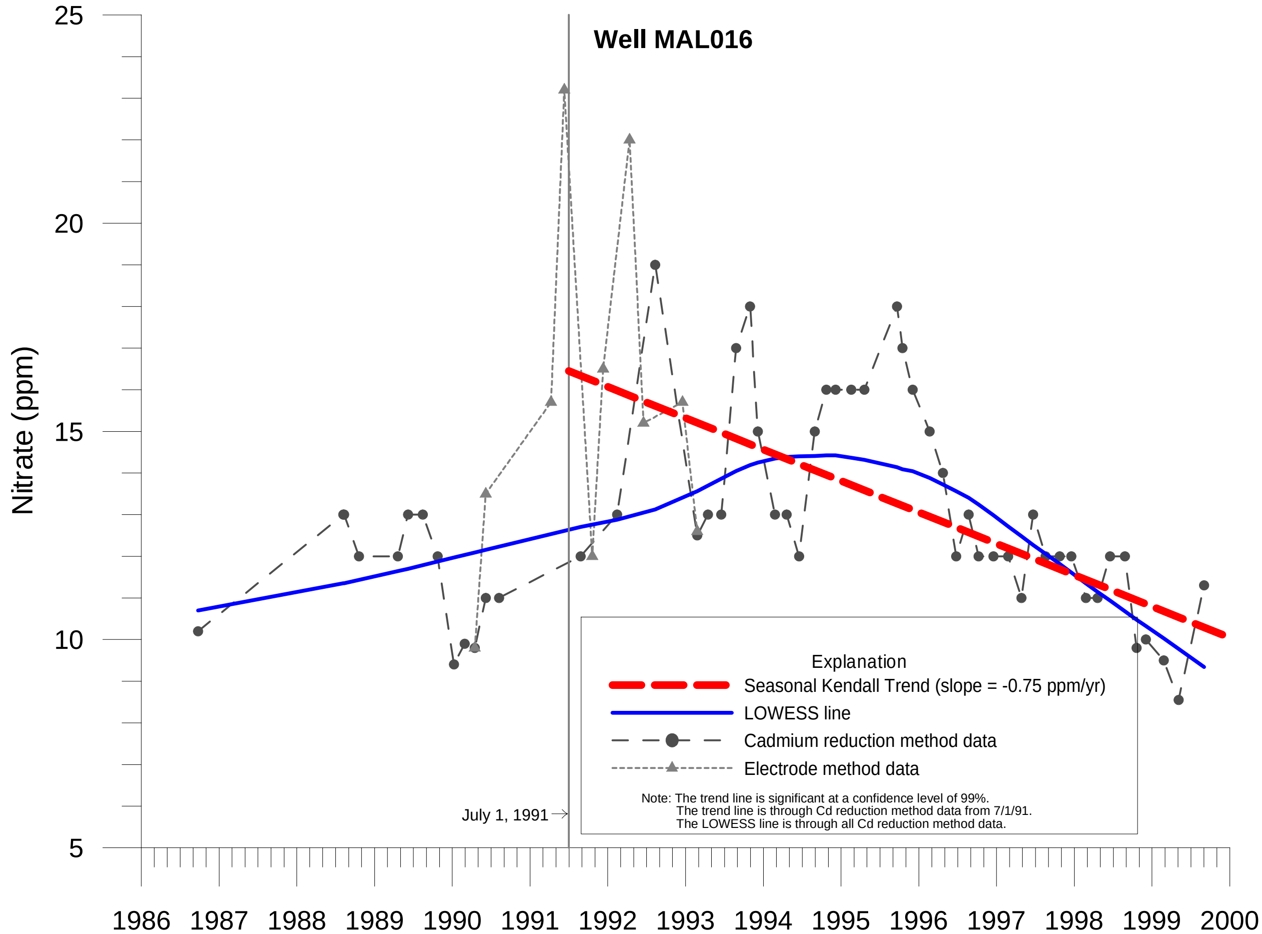
The variance tests summarized above (the F-test and Levene's test) evaluate the data presented in Figures C-1 through C-4 for wells MAL030, MAL041, MAL044, and OWY101. The low P-values indicate the variances of the cadmium reduction method data and the electrode method data are statistically different at confidence levels of 95% (P-values <0.05) to 99% (P-values <0.01).


Well MAL005
Nitrate (ppm)
Explanation
Seasonal Kendall Trend (slope = 0.38 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

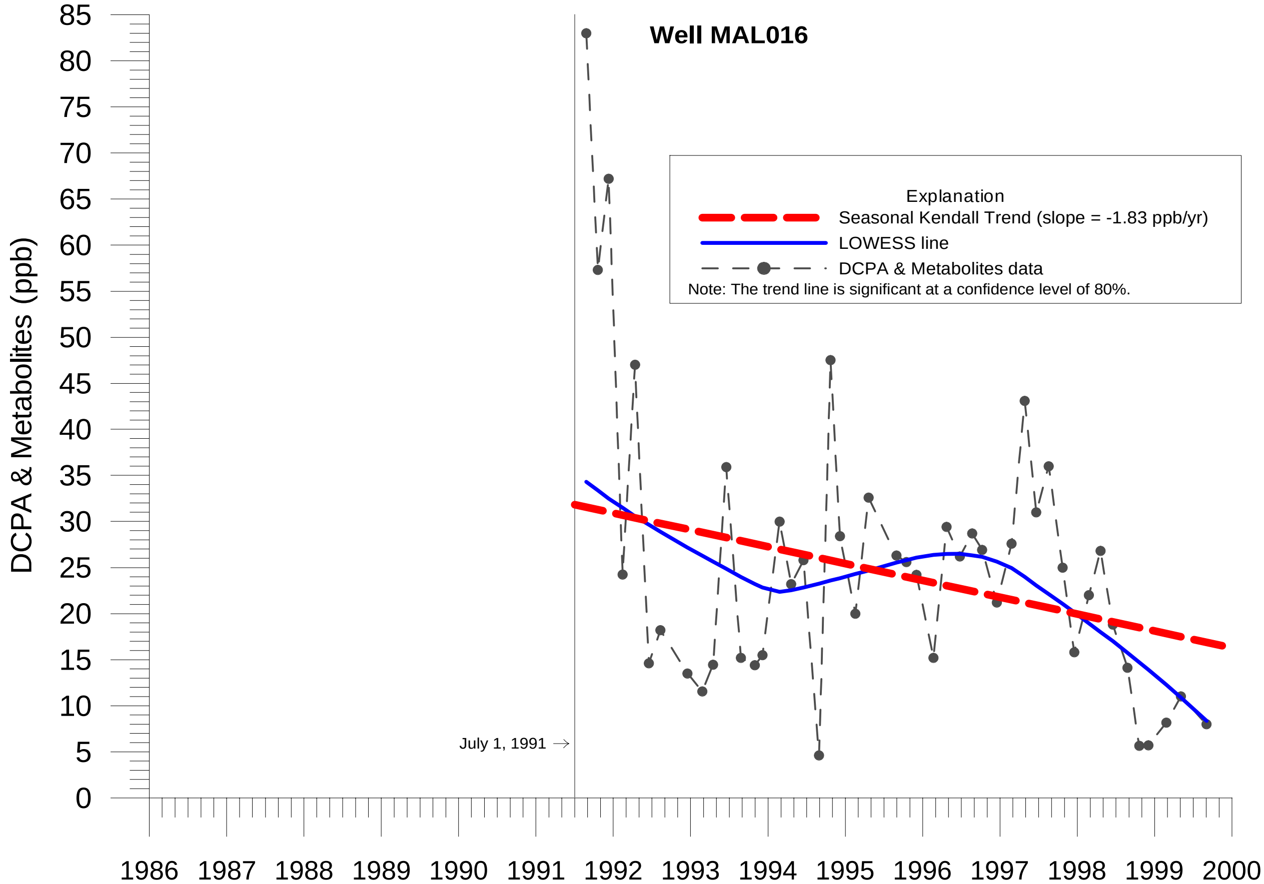

Well MAL005
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = 1.77 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
July 1, 1991
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Well MAL012
Nitrate (ppm)
Explanation
Seasonal Kendall Trend (slope = -0.89 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 95%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
40
35
30
25
20
15
10
5
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

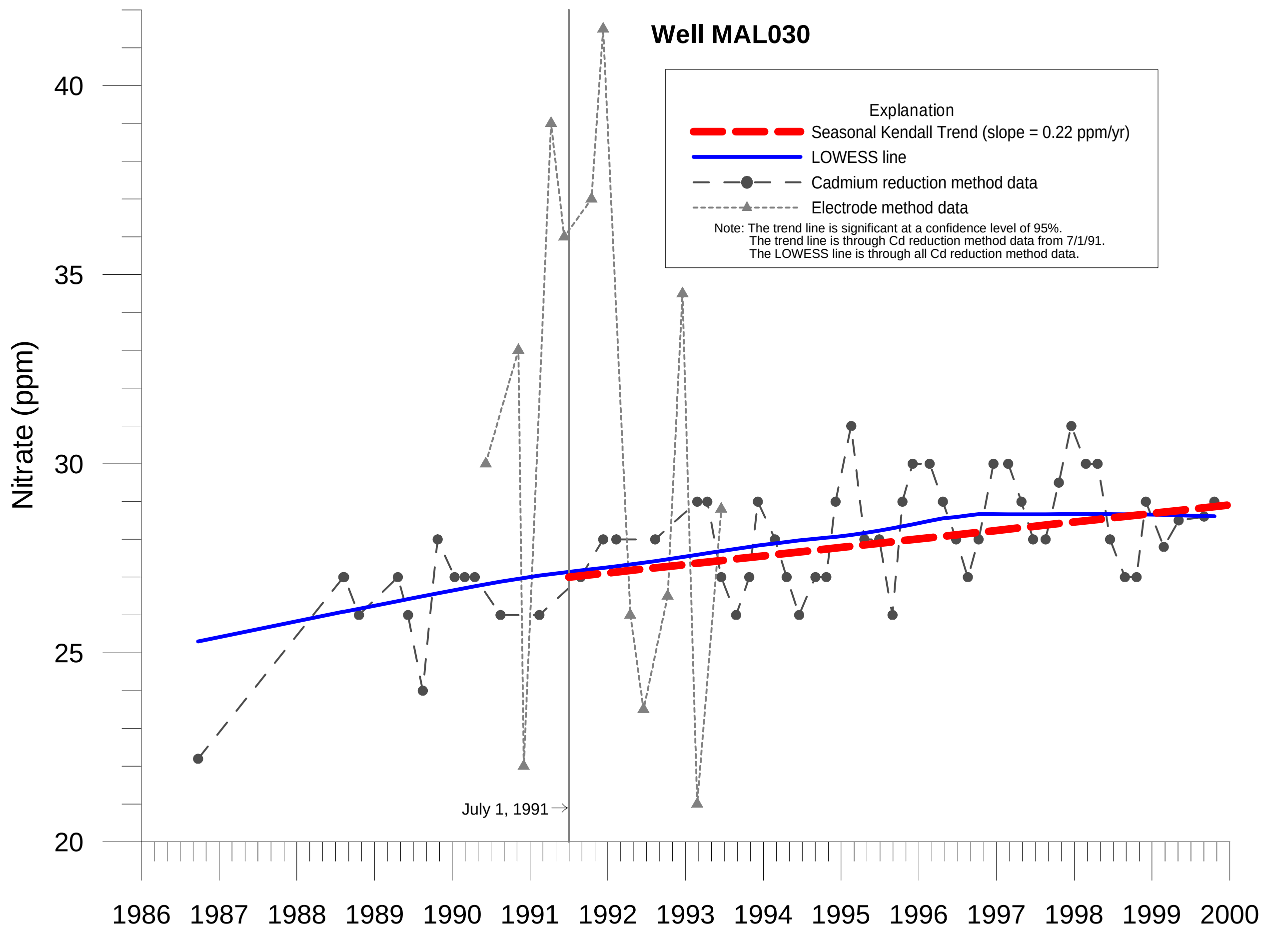

Well MAL012
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = -14.55 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 80%.
July 1, 1991
800
700
600
500
400
300
200
100
0
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

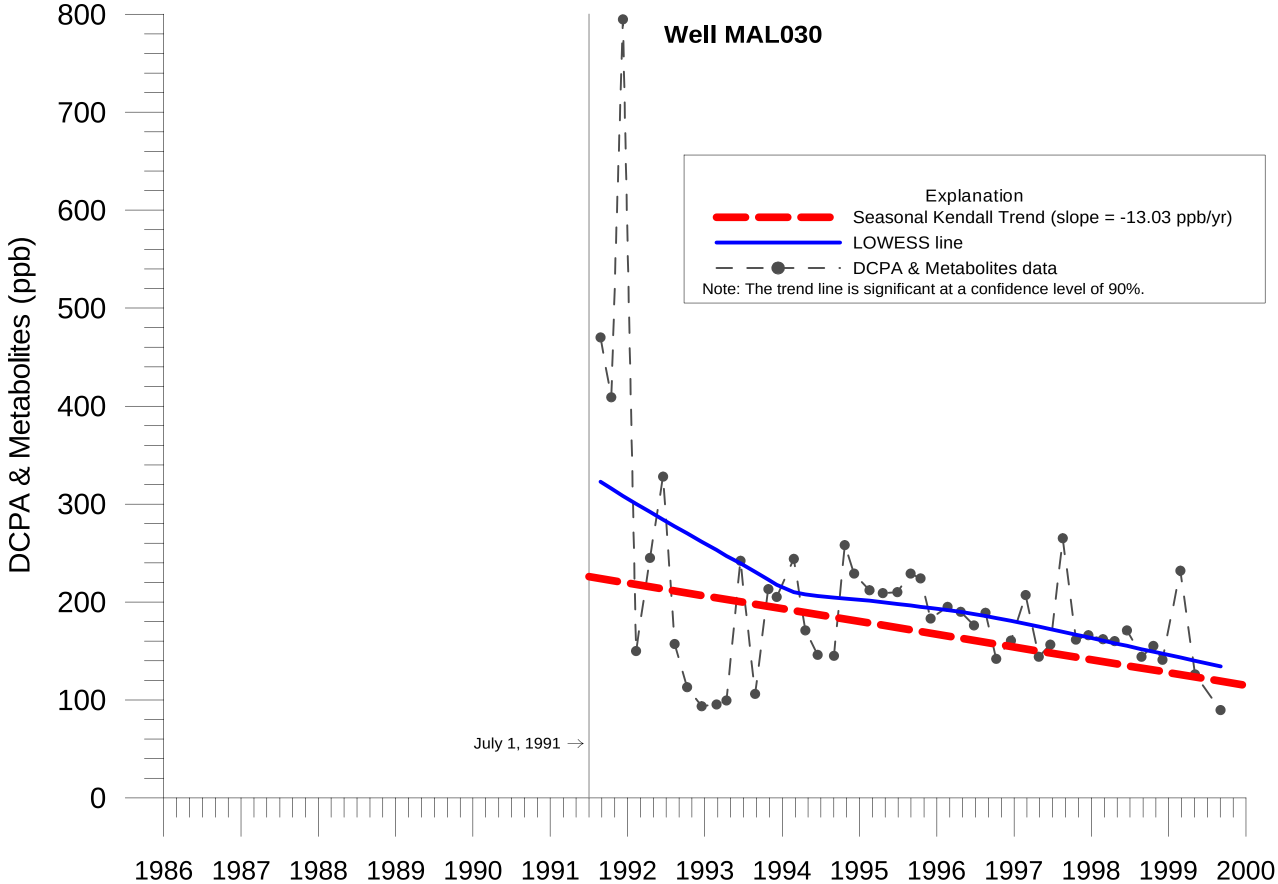


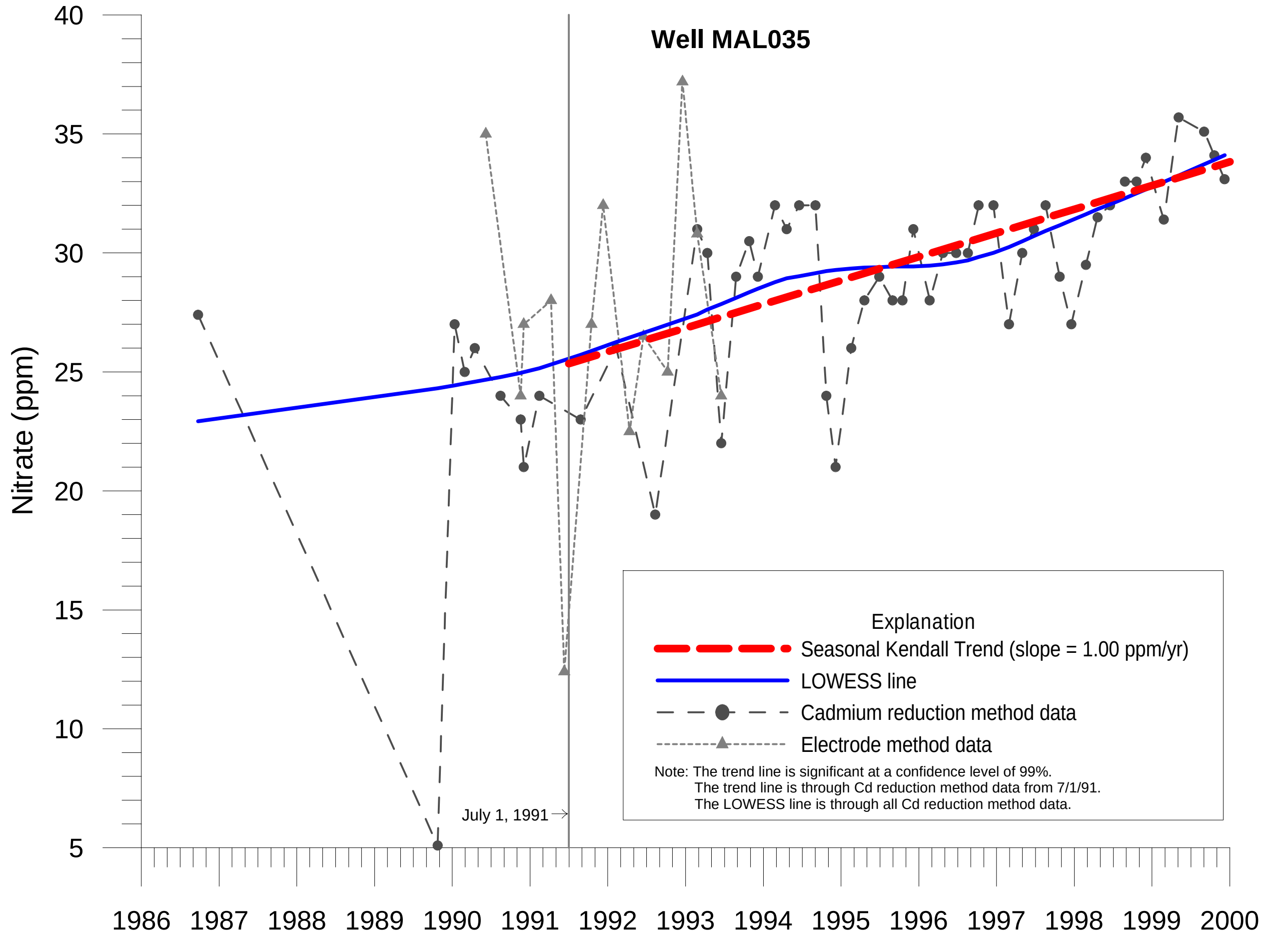
Well MAL016
Nitrate (ppm)
Explanation
Seasonal Kendall Trend (slope = -0.75 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991



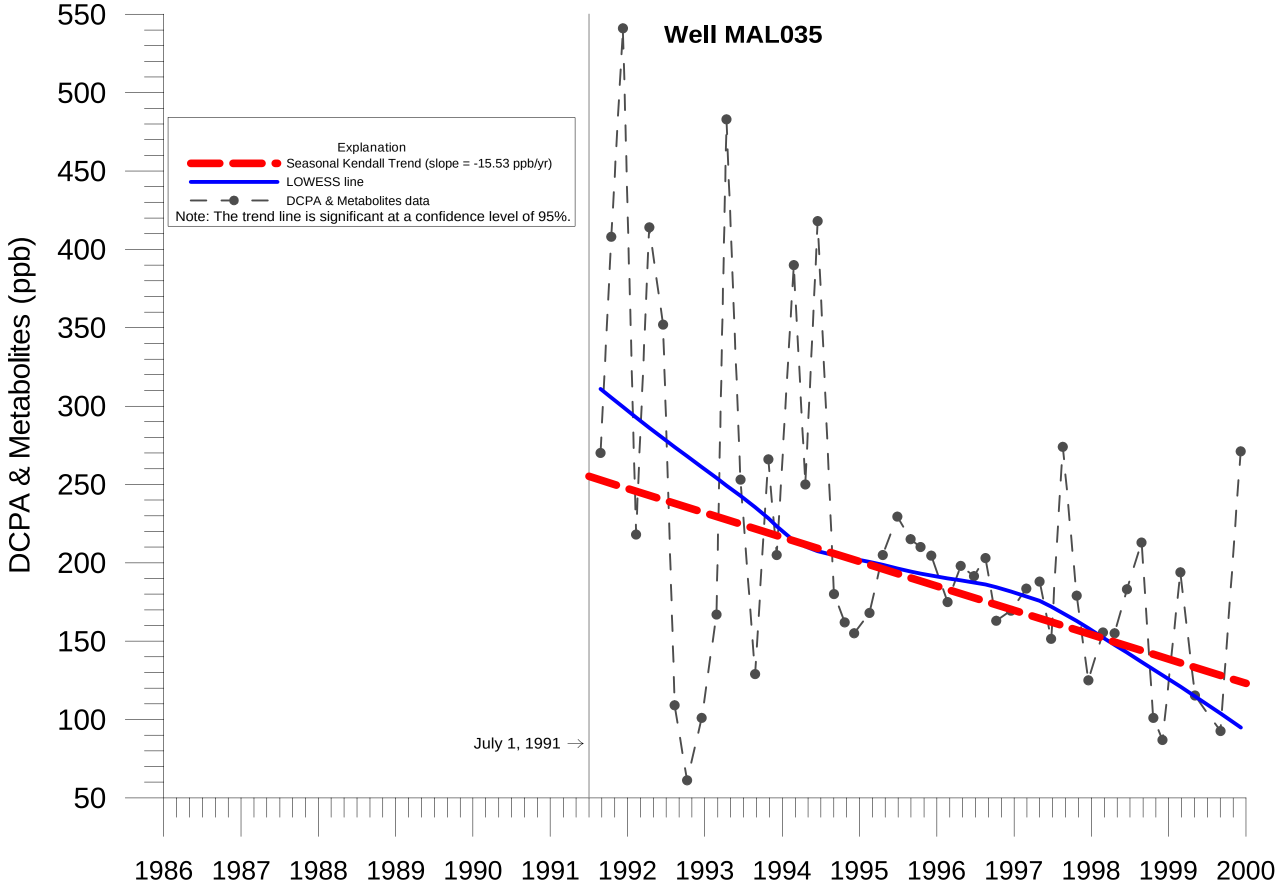
Well MAL016
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = -1.83 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 80%.
July 1, 1991


Well MAL030
Explanation
Seasonal Kendall Trend (slope = 0.22 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 95%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
Nitrate (ppm)
20
25
30
35
40
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

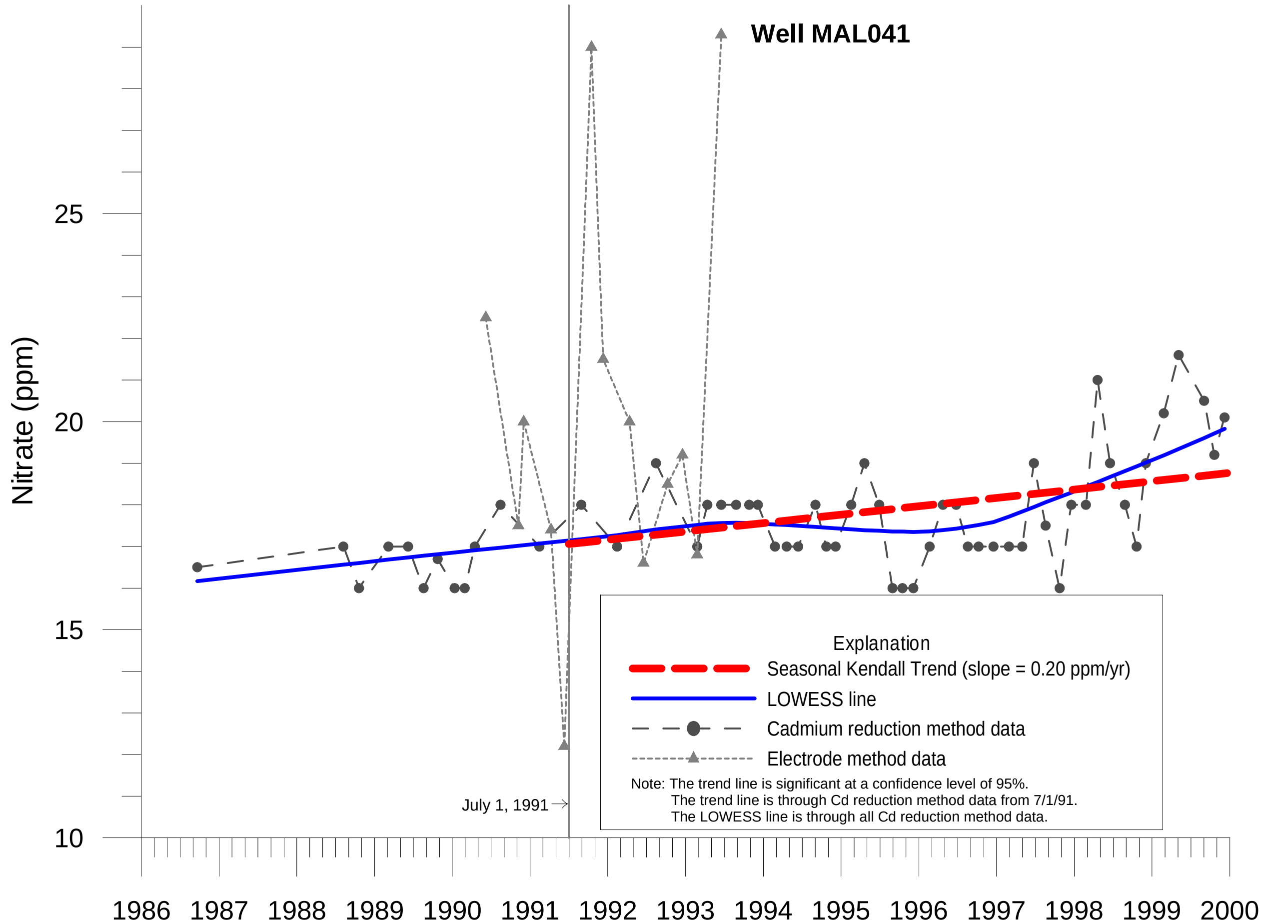

Well MAL030
Explanation
Seasonal Kendall Trend (slope = -13.03 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 90%.
July 1, 1991
DCPA & Metabolites (ppb)
0
100
200
300
400
500
600
700
800
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

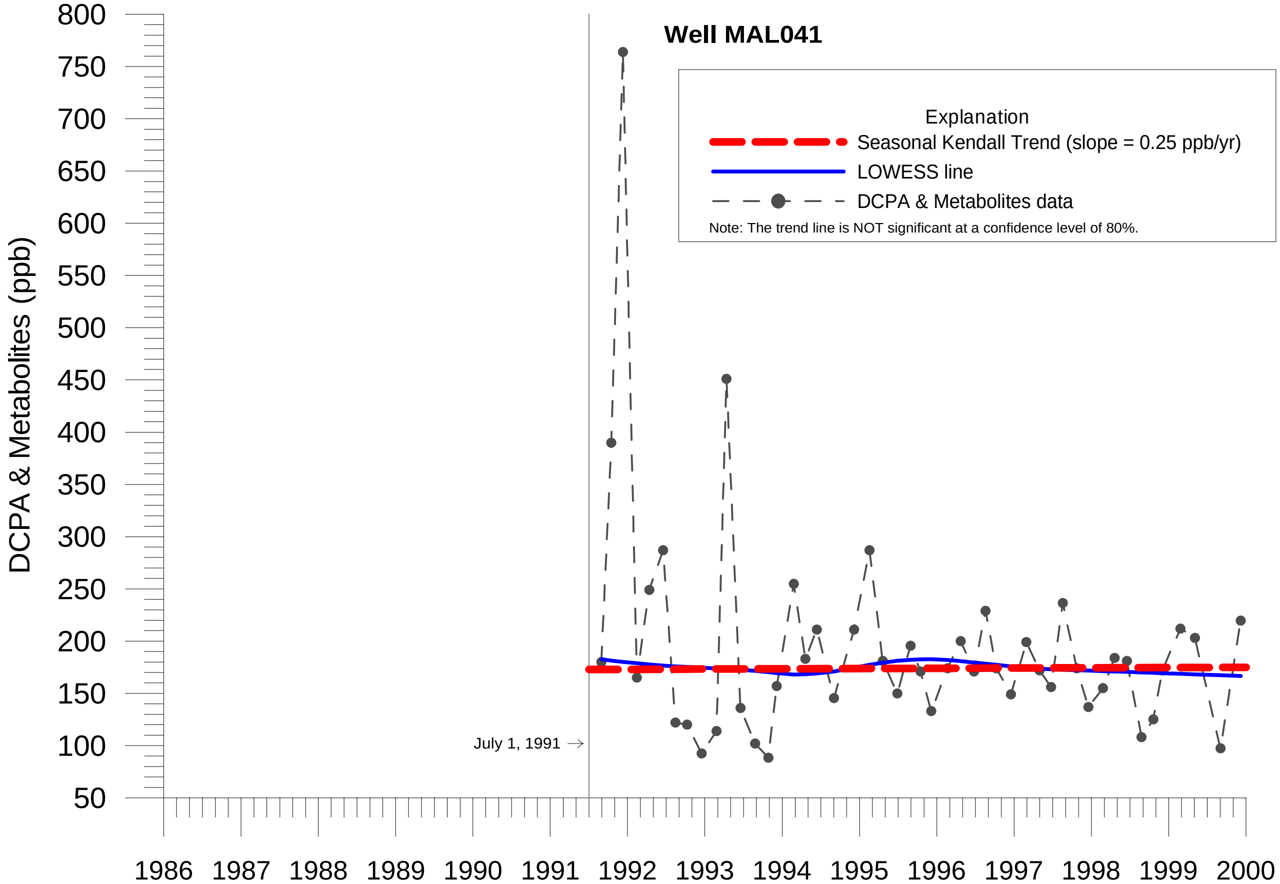


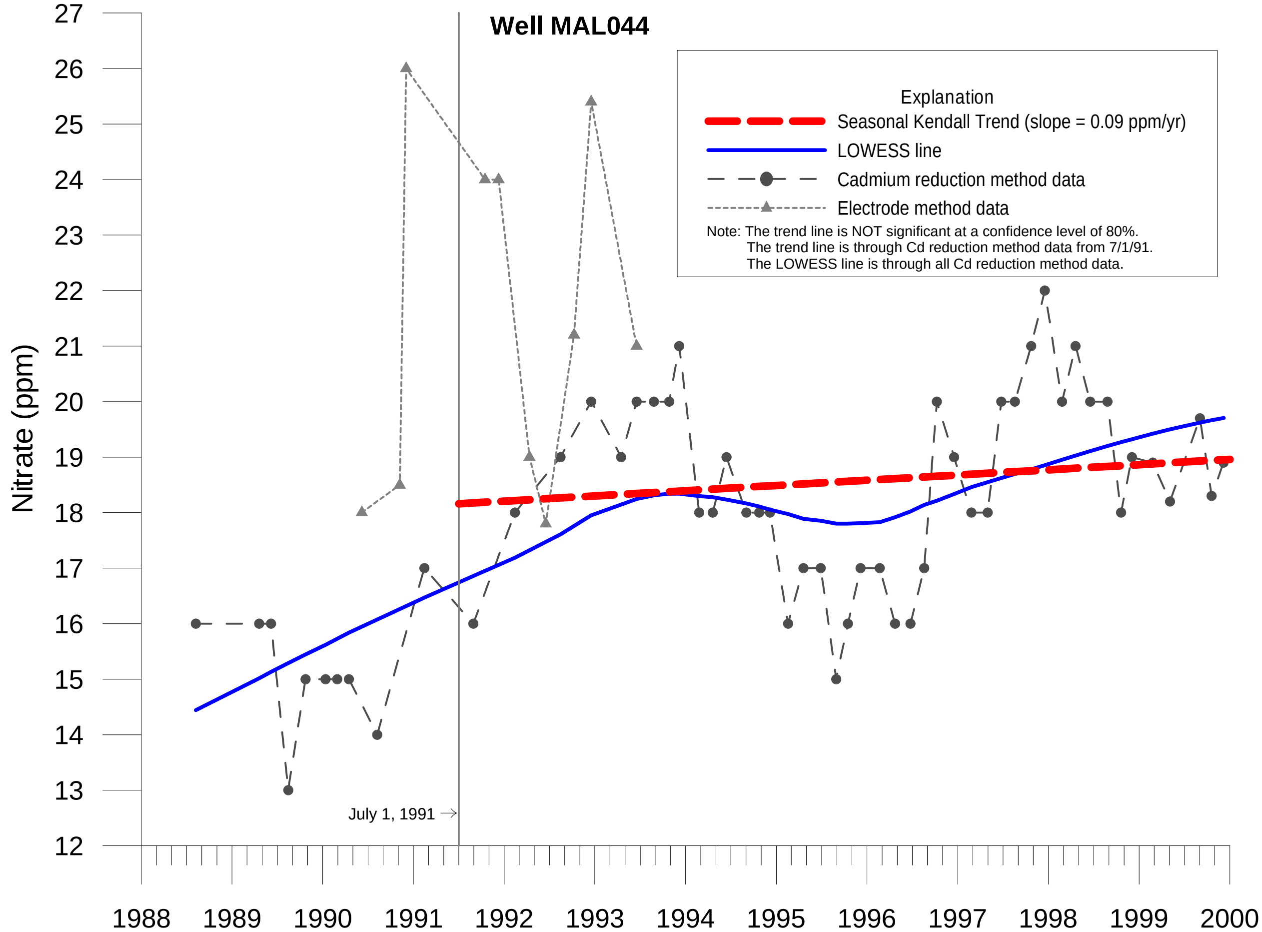
Well MAL035
Nitrate (ppm)
40
35
30
25
20
15
10
5
July 1, 1991
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
Explanation
Seasonal Kendall Trend (slope = 1.00 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

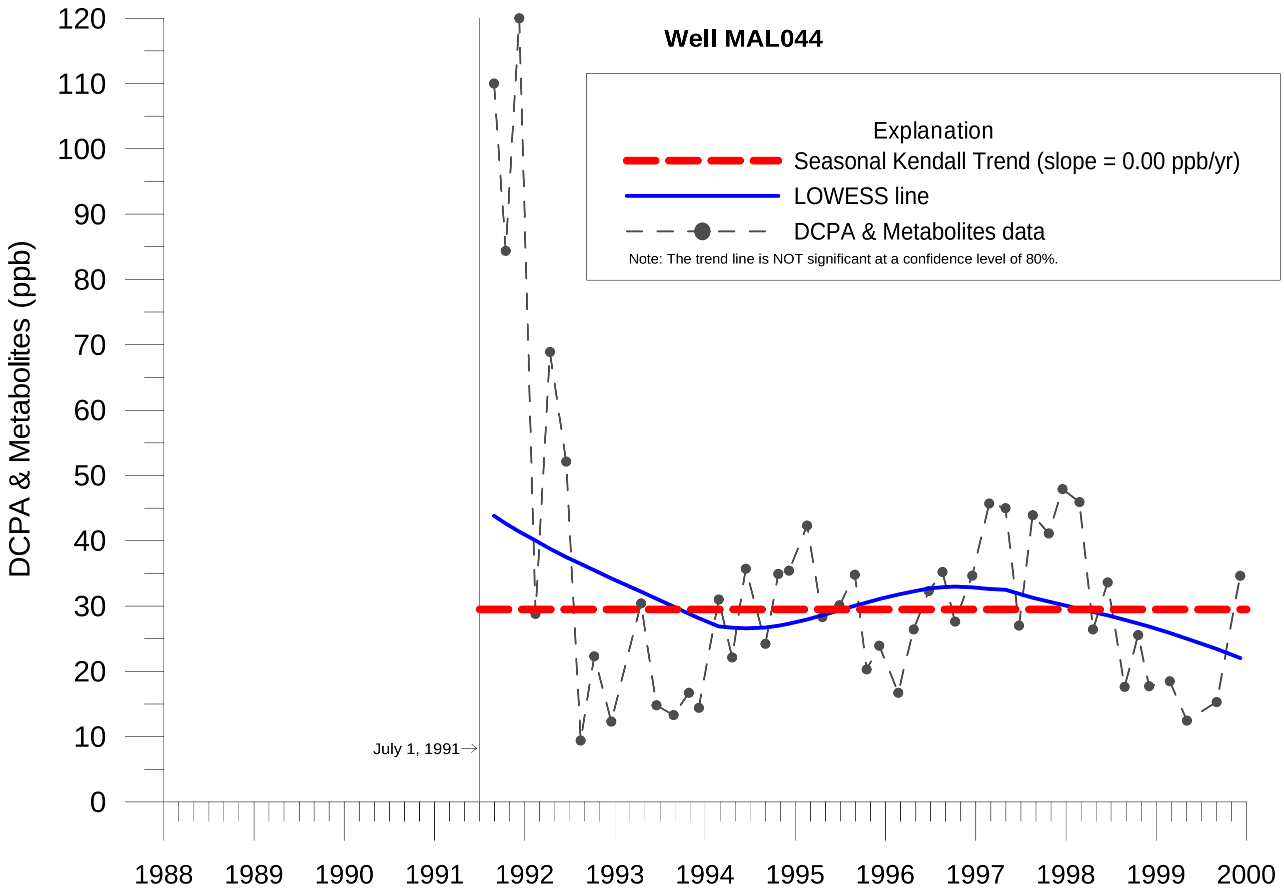


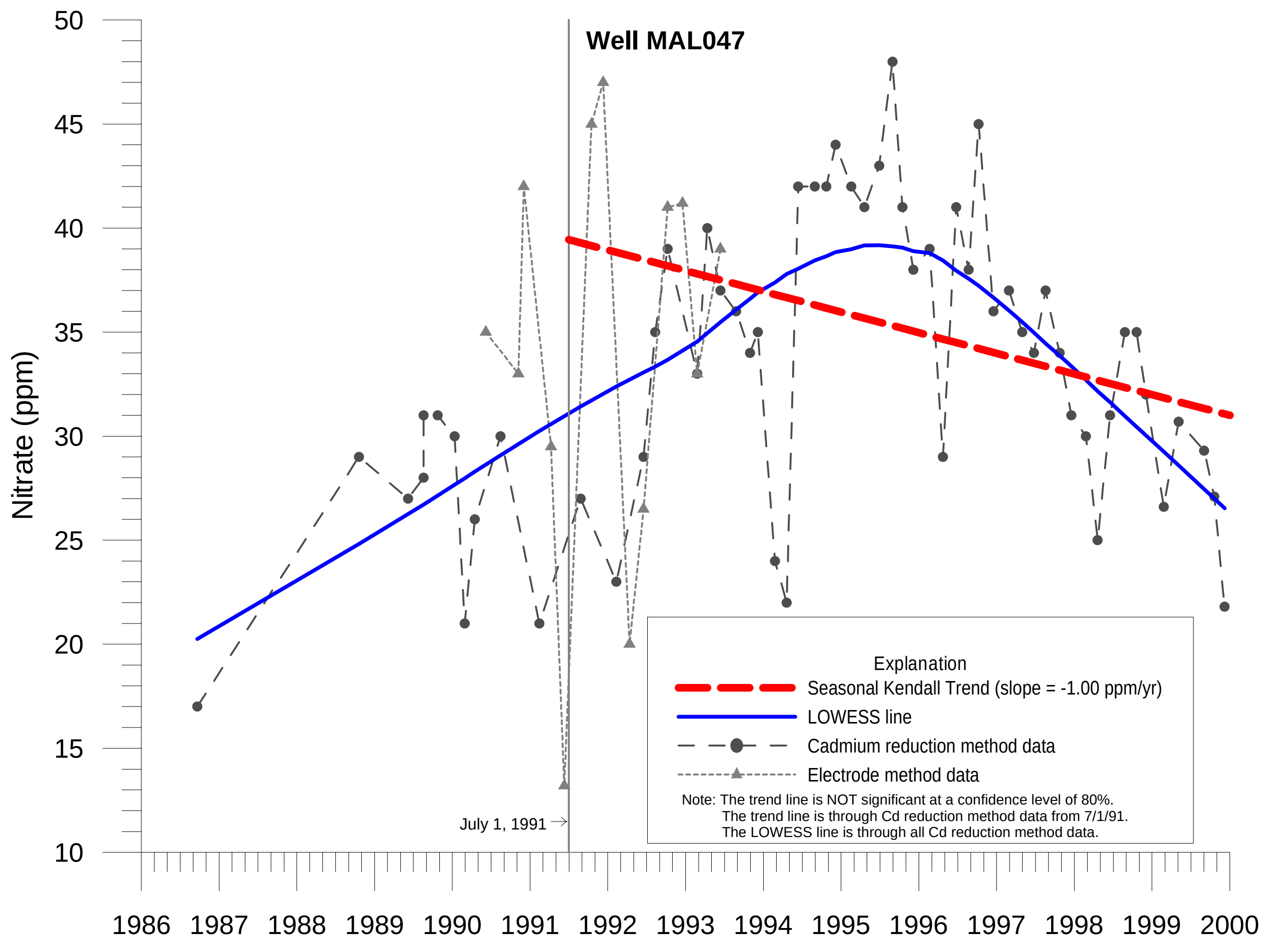
Well MAL035
DCPA & Metabolites (ppb)
550
500
450
400
350
300
250
200
150
100
50
Explanation
Seasonal Kendall Trend (slope = -15.53 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 95%.
July 1, 1991
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

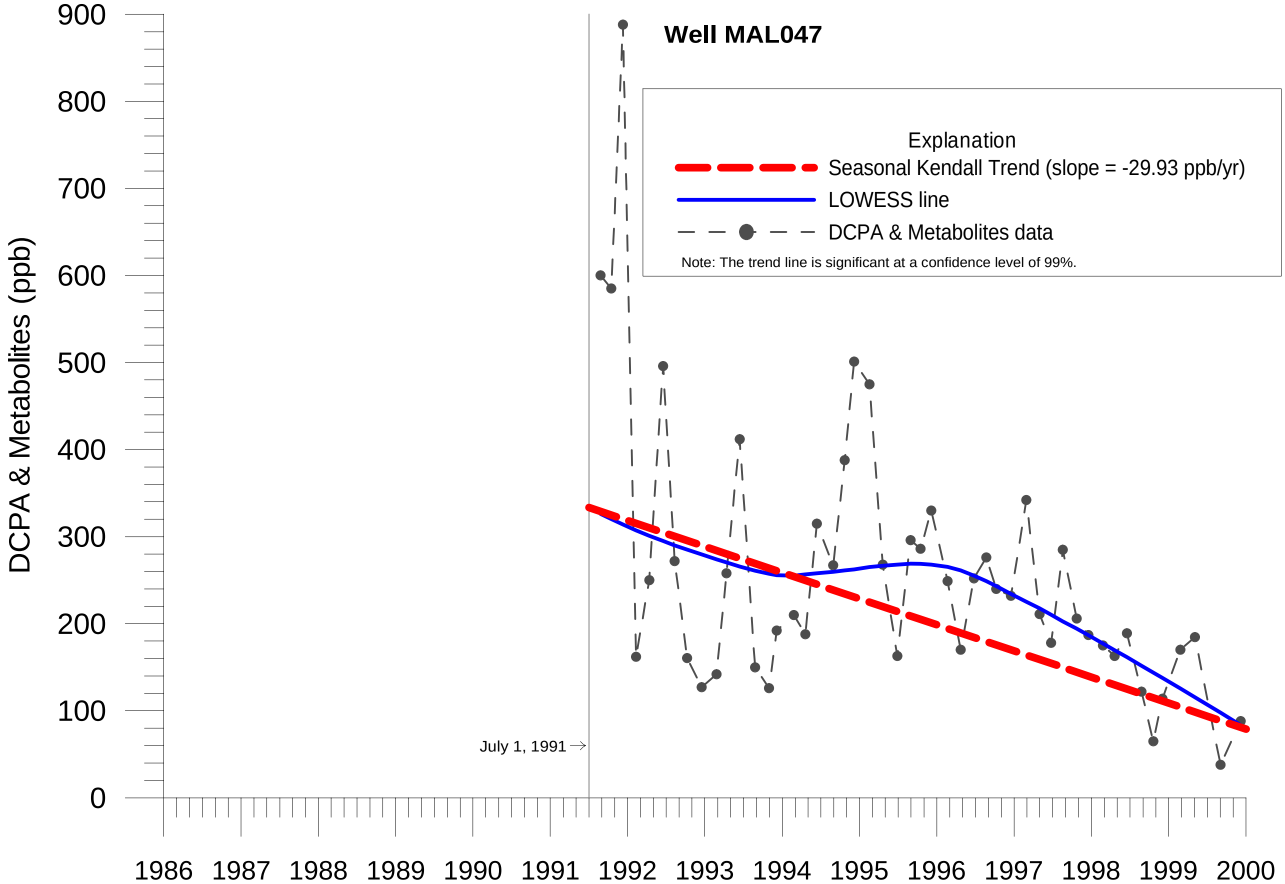

Well MAL041
Nitrate (ppm)
25
20
15
10
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 0.20 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 95%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

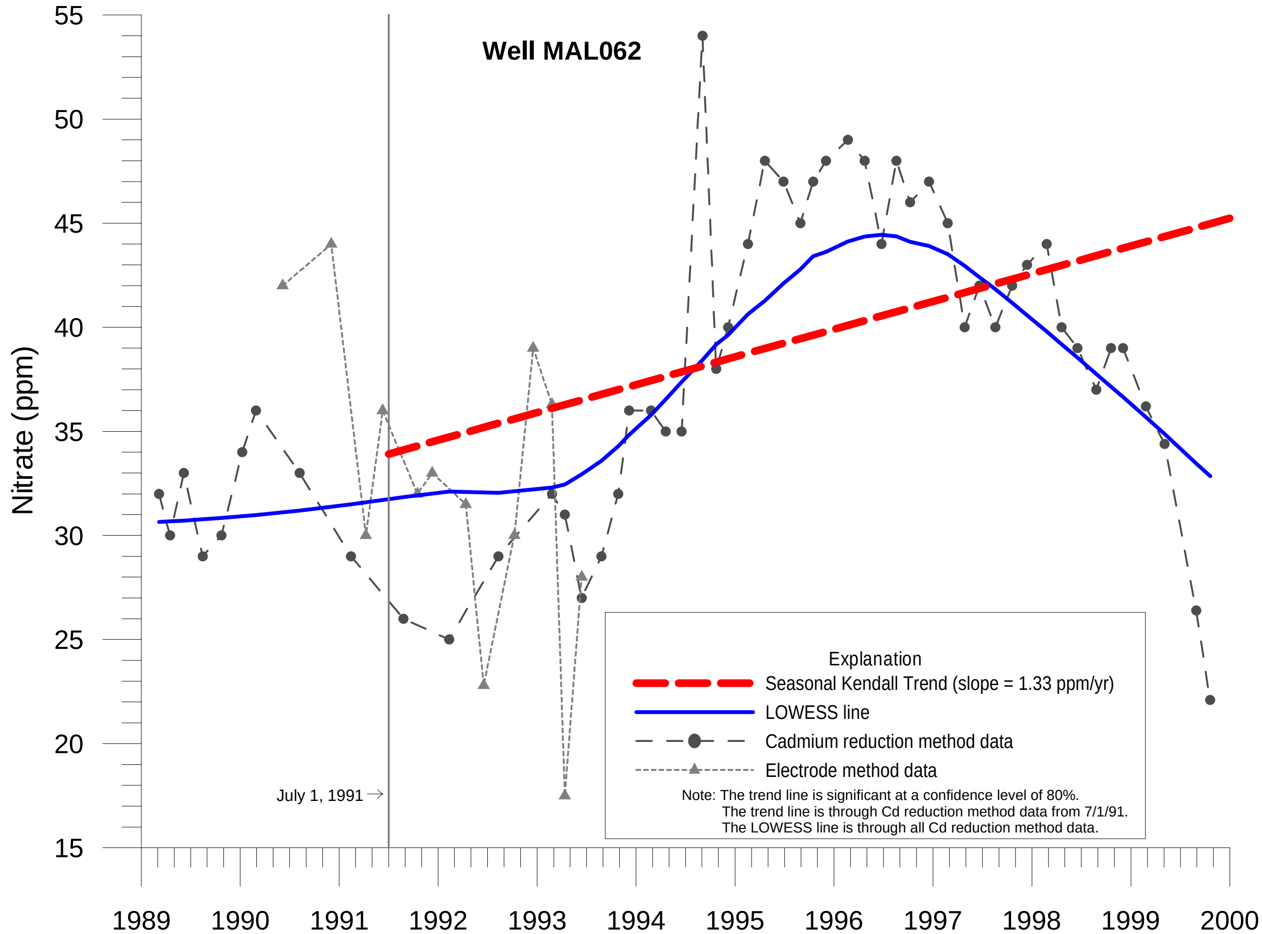

Well MAL041
DCPA & Metabolites (ppb)
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 0.25 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.

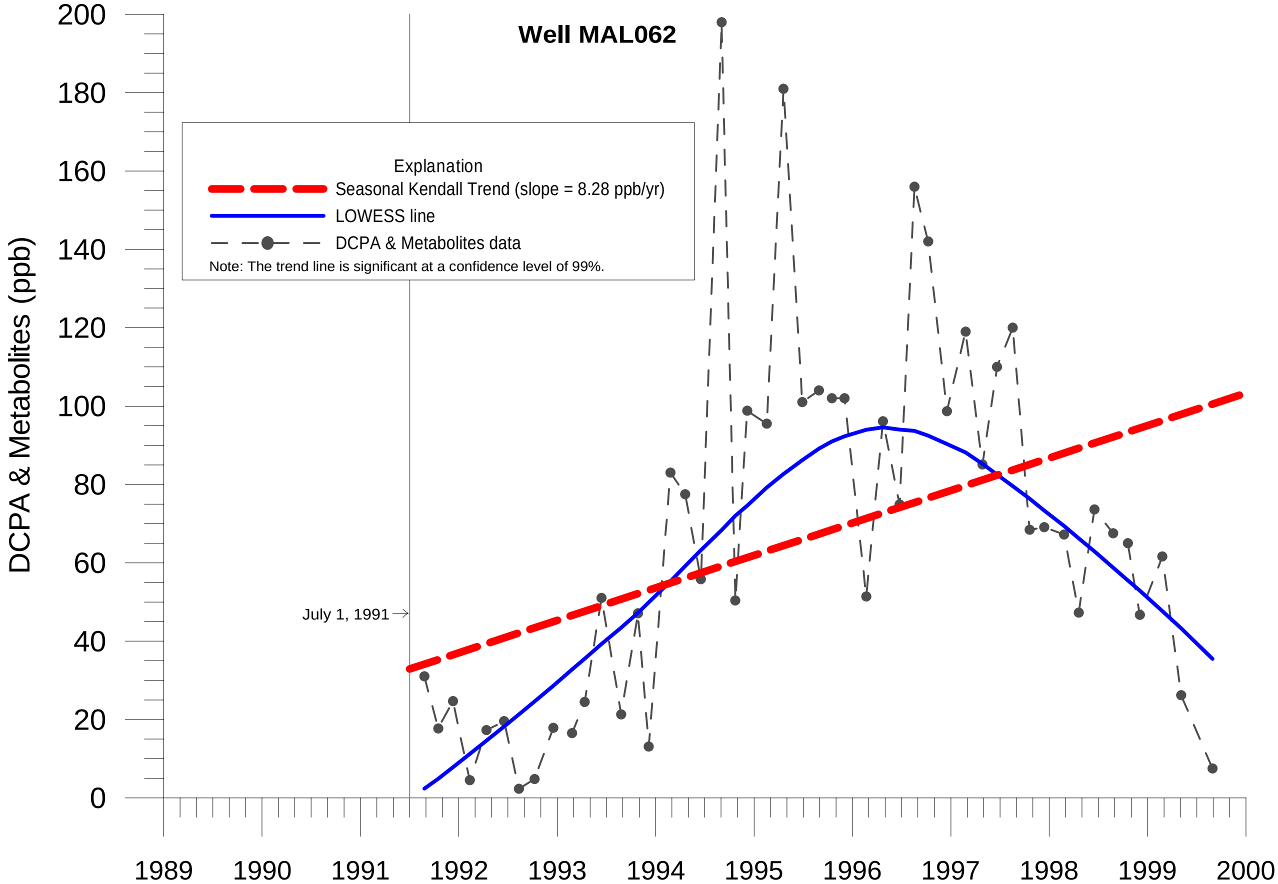

Well MAL044
Explanation
Seasonal Kendall Trend (slope = 0.09 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

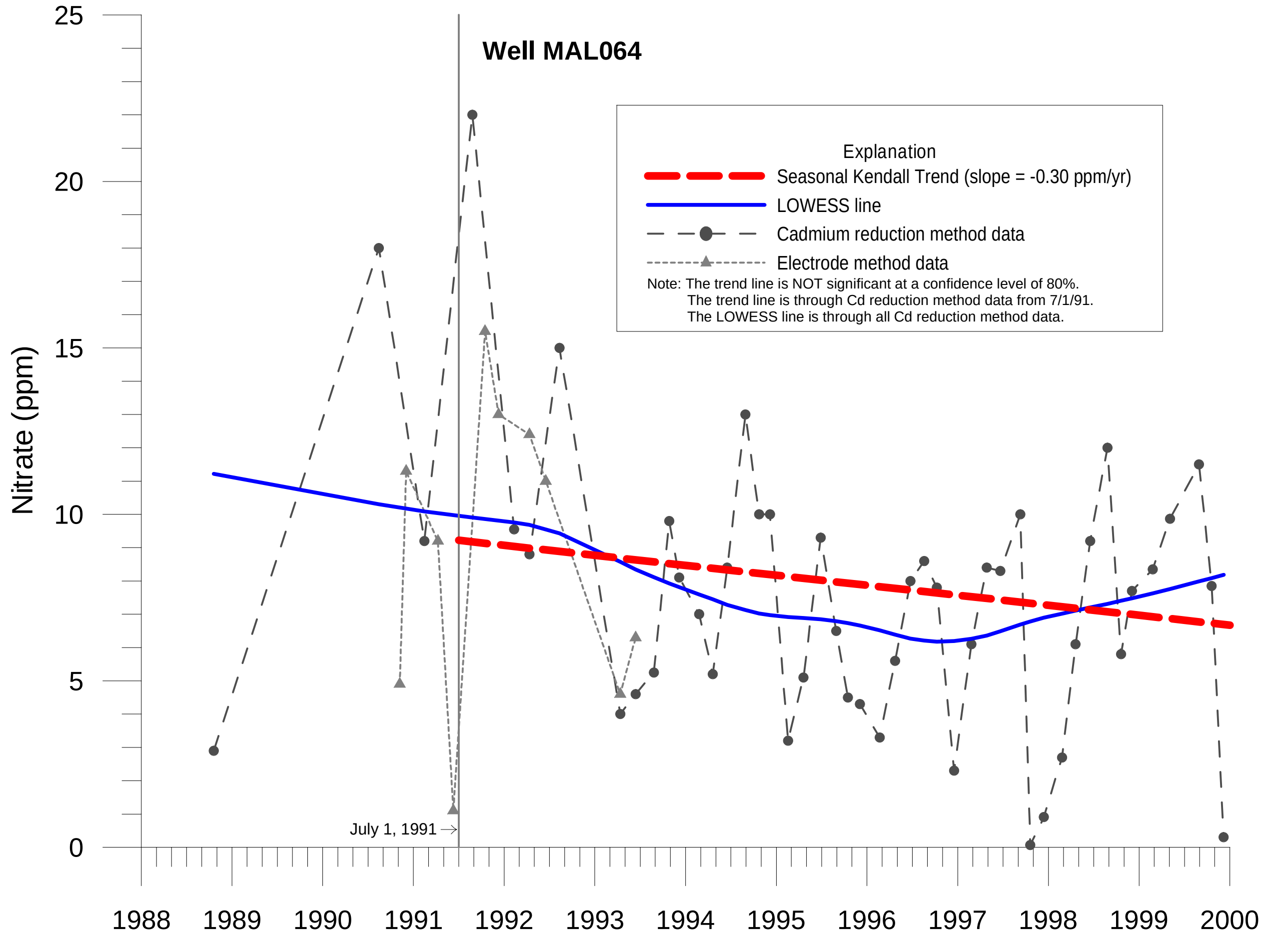

Well MAL044
Explanation
Seasonal Kendall Trend (slope = 0.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991
0
10
20
30
40
50
60
70
80
90
100
110
120
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Well MAL047
Nitrate (ppm)
50
45
40
35
30
25
20
15
10
July 1, 1991
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
Explanation
Seasonal Kendall Trend (slope = -1.00 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

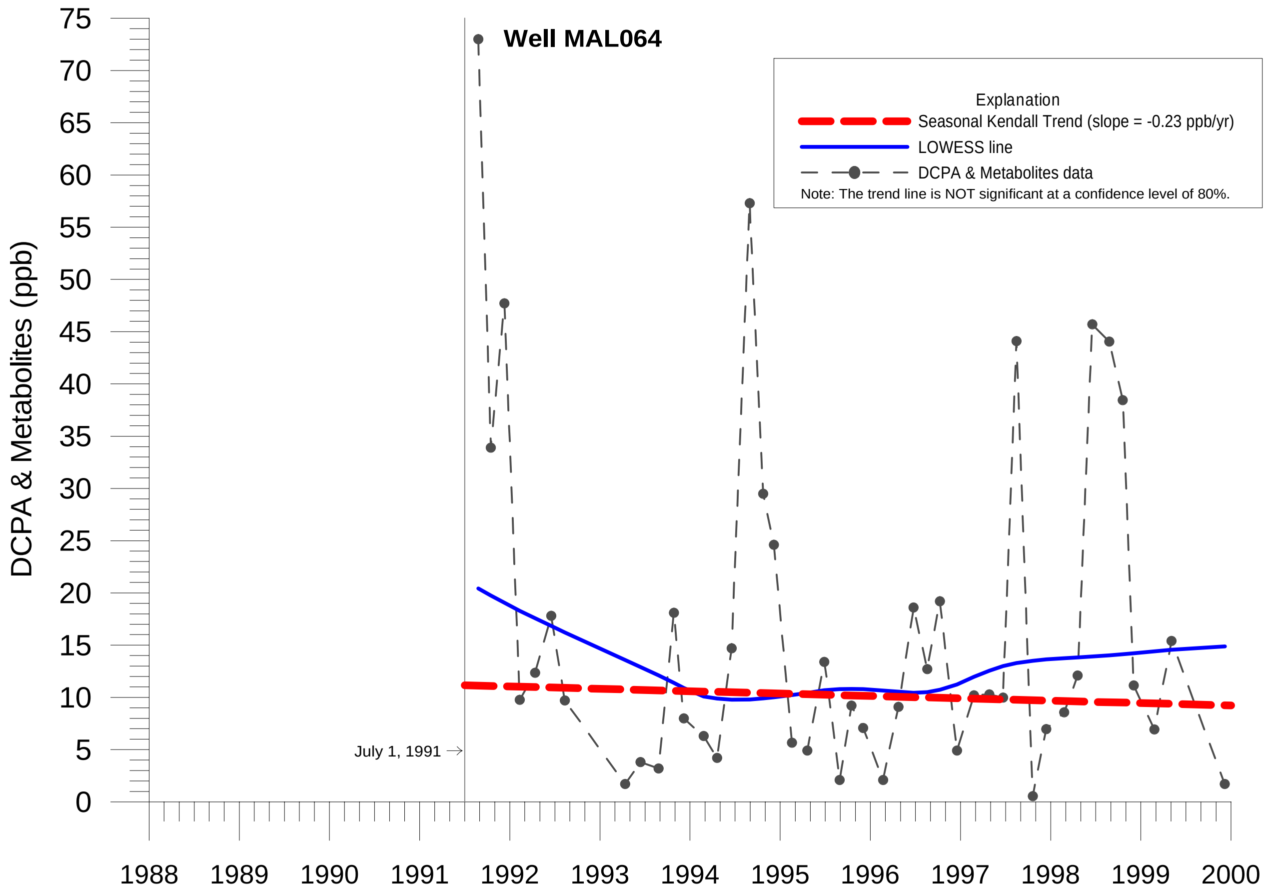

Well MAL047
DCPA & Metabolites (ppb)
900
800
700
600
500
400
300
200
100
0
July 1, 1991
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
Explanation
Seasonal Kendall Trend (slope = -29.93 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.


Well MAL062
Nitrate (ppm)
55
50
45
40
35
30
25
20
15
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 1.33 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

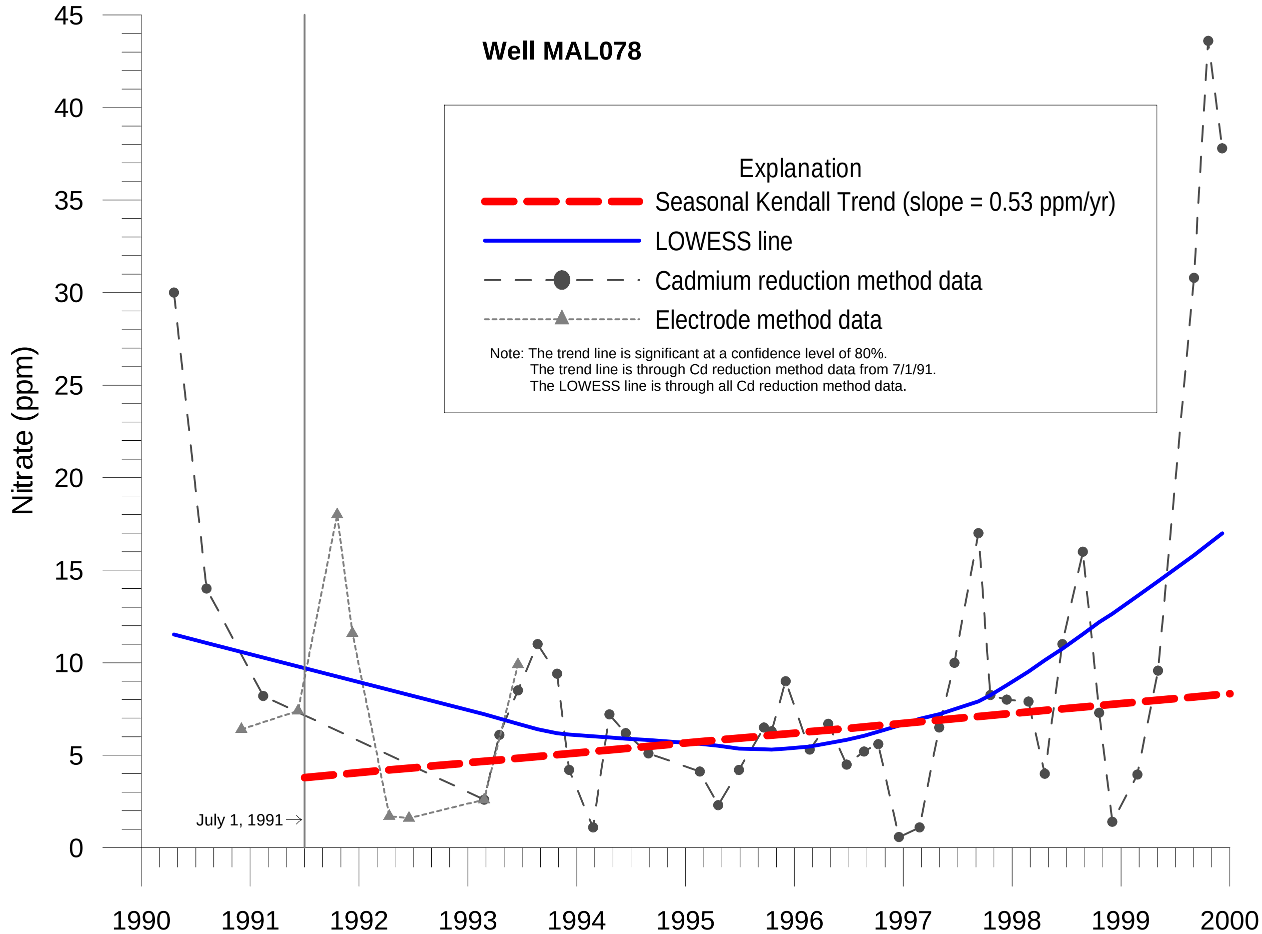

Well MAL062
DCPA & Metabolites (ppb)
200
180
160
140
120
100
80
60
40
20
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 8.28 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.

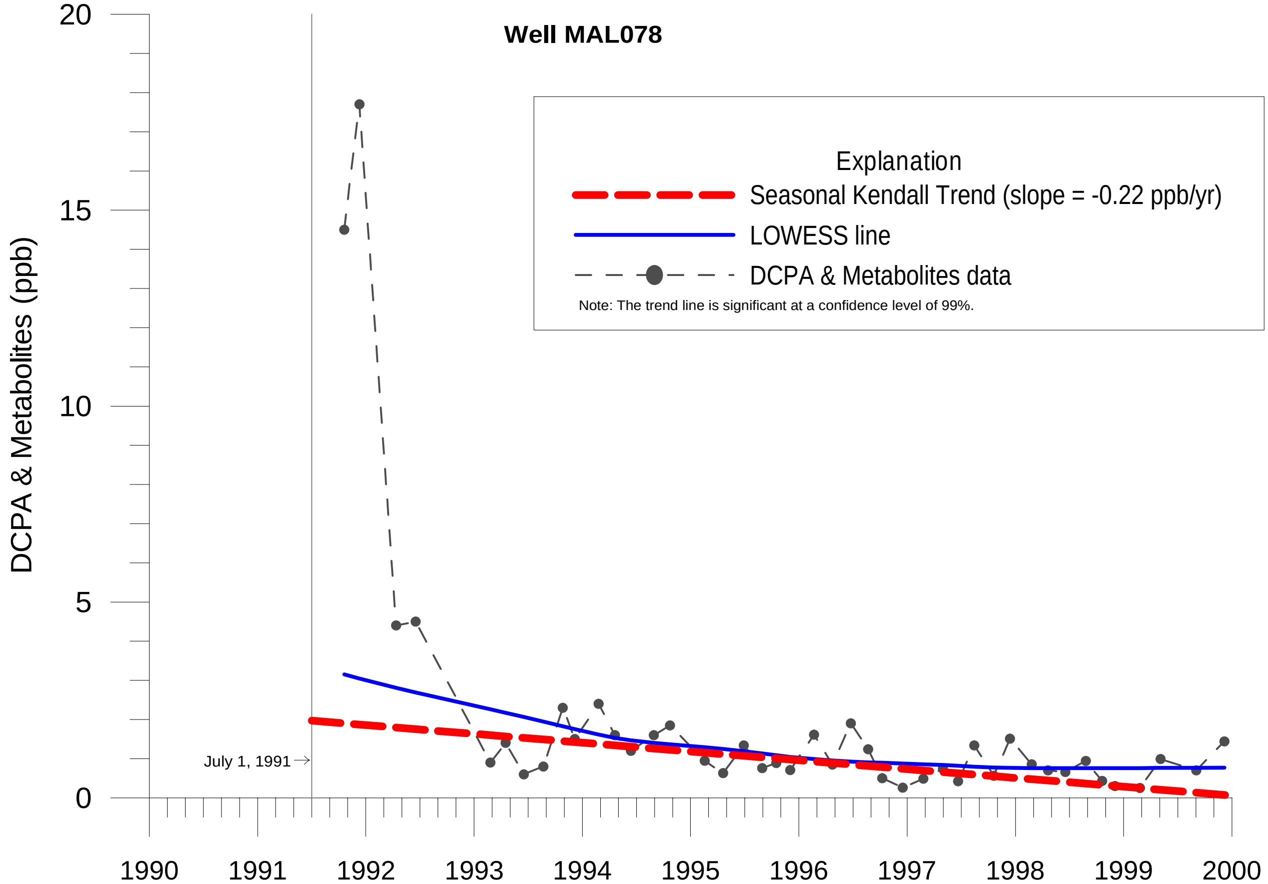


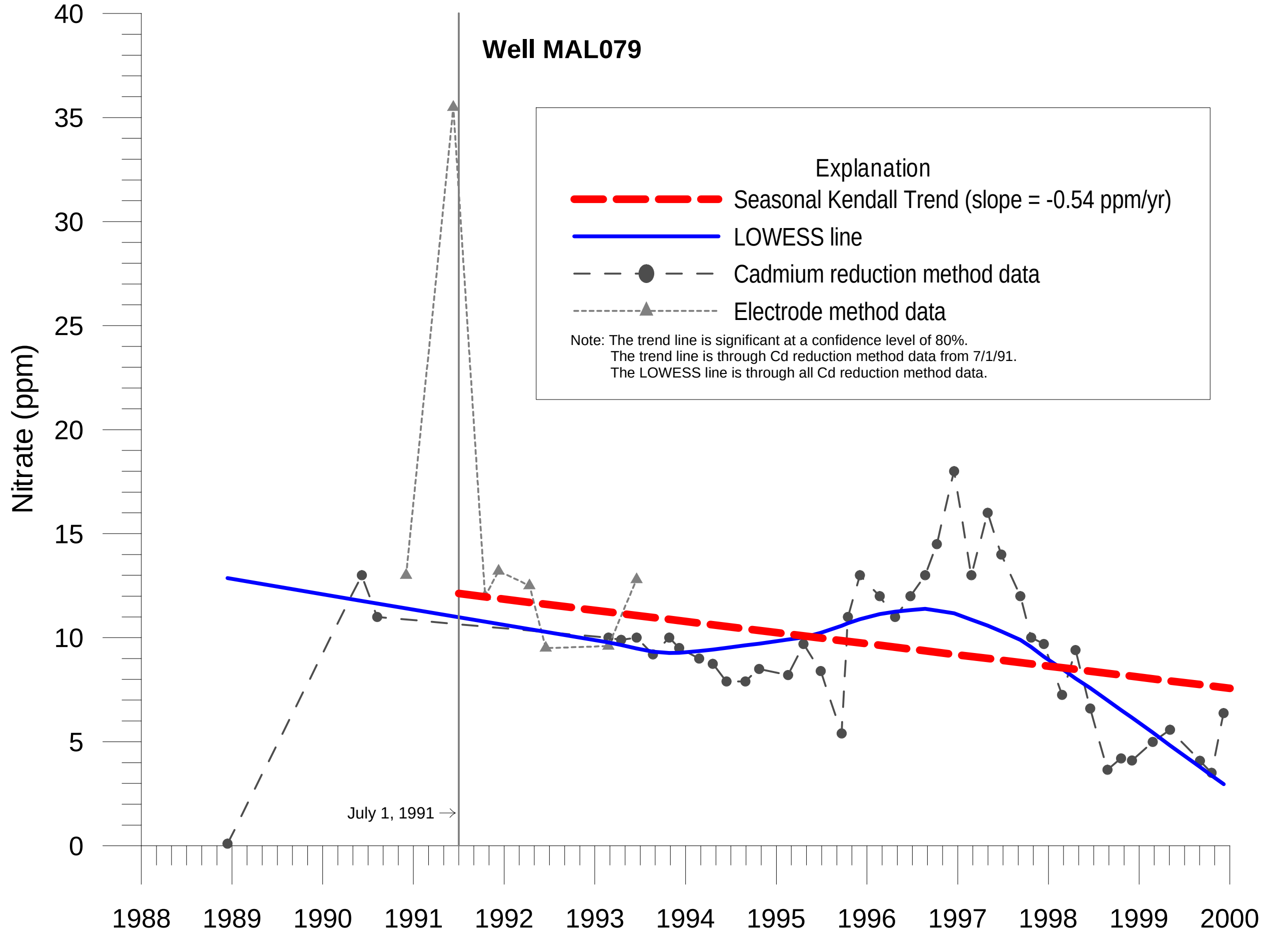
Well MAL064
Explanation
Seasonal Kendall Trend (slope = -0.30 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991 →
0
5
10
15
20
25
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

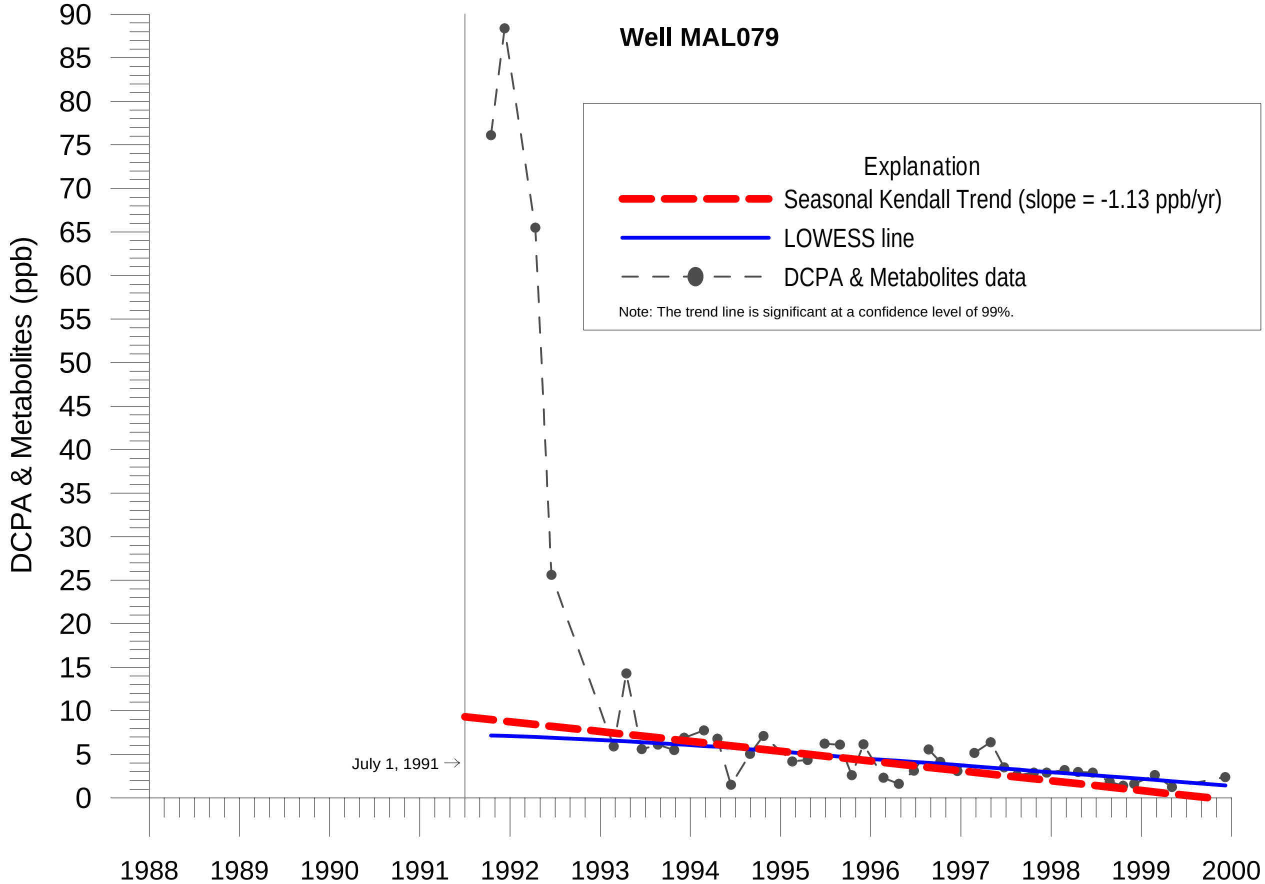


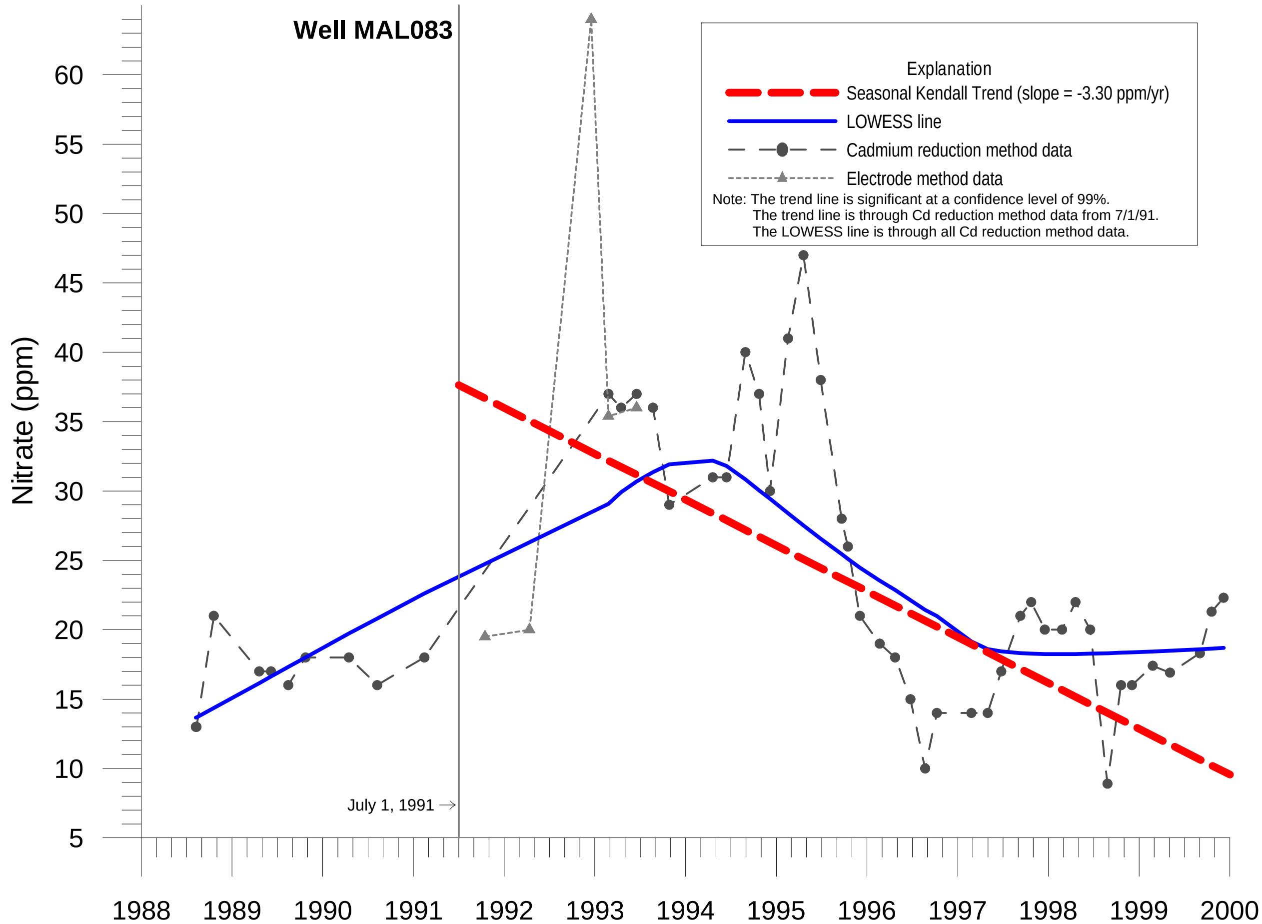
Well MAL064
Explanation
Seasonal Kendall Trend (slope = -0.23 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991 →
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

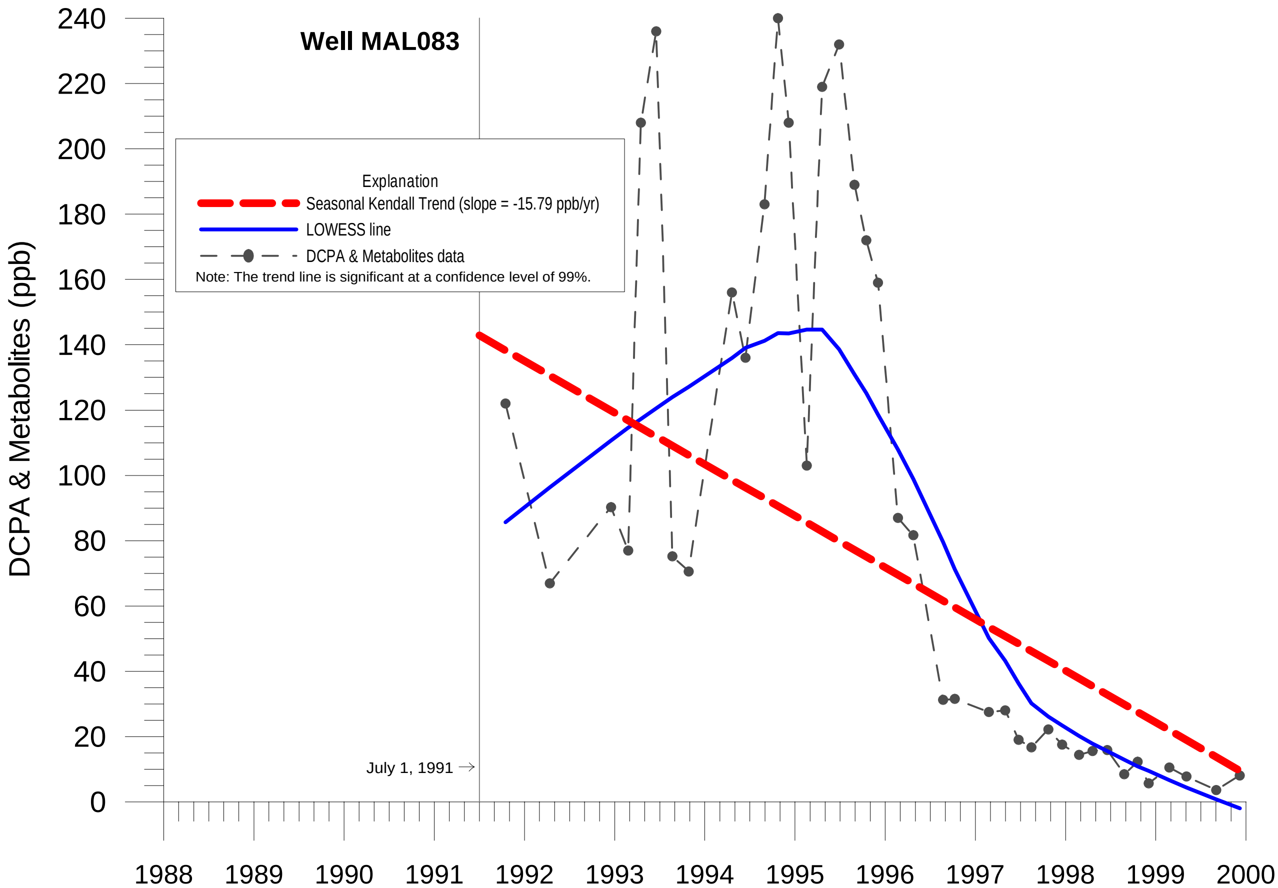

Well MAL078
Explanation
Seasonal Kendall Trend (slope = 0.53 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
0
5
10
15
20
25
30
35
40
45
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

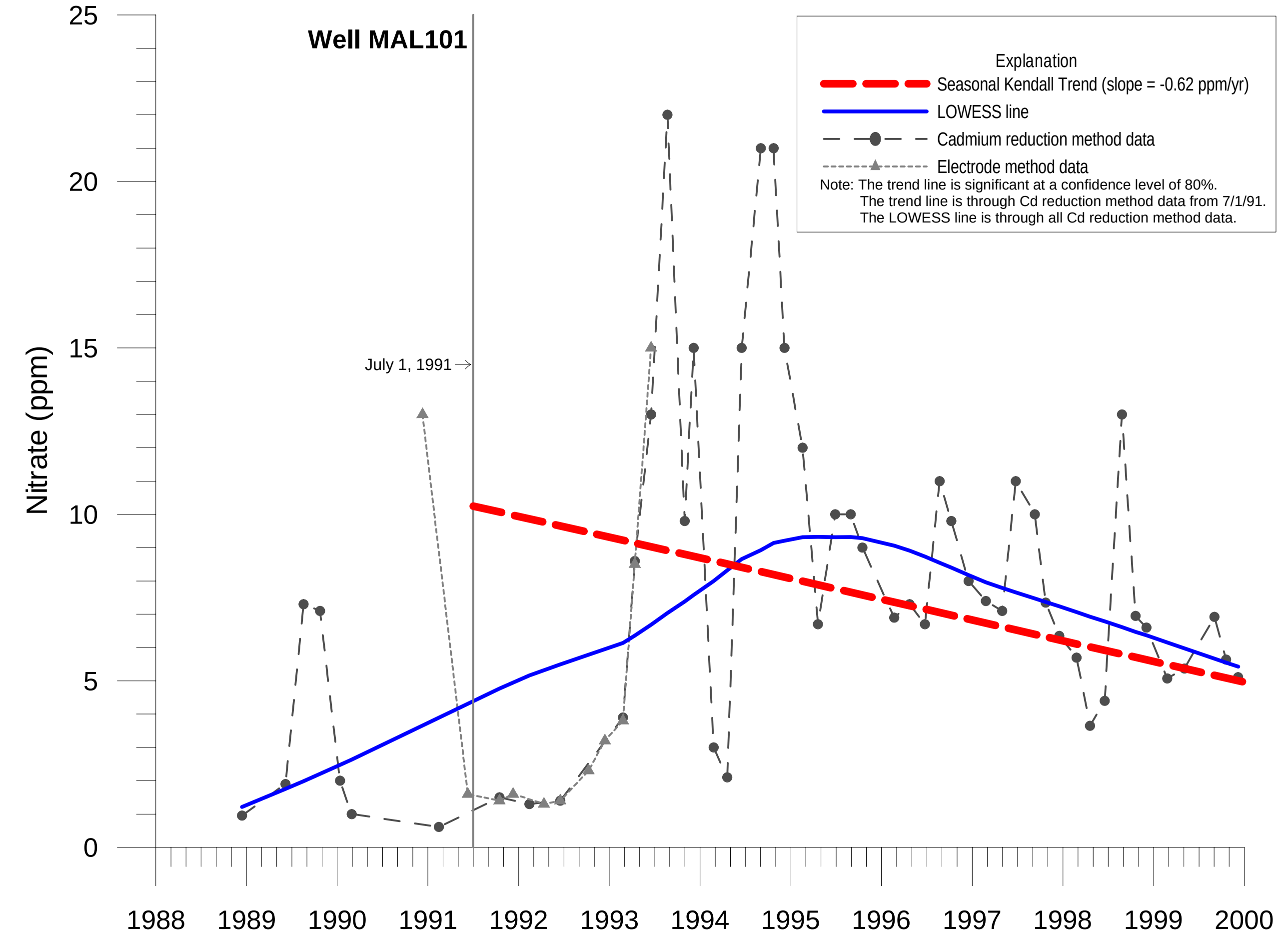

Well MAL078
Explanation
Seasonal Kendall Trend (slope = -0.22 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
DCPA & Metabolites (ppb)
July 1, 1991
0
5
10
15
20
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

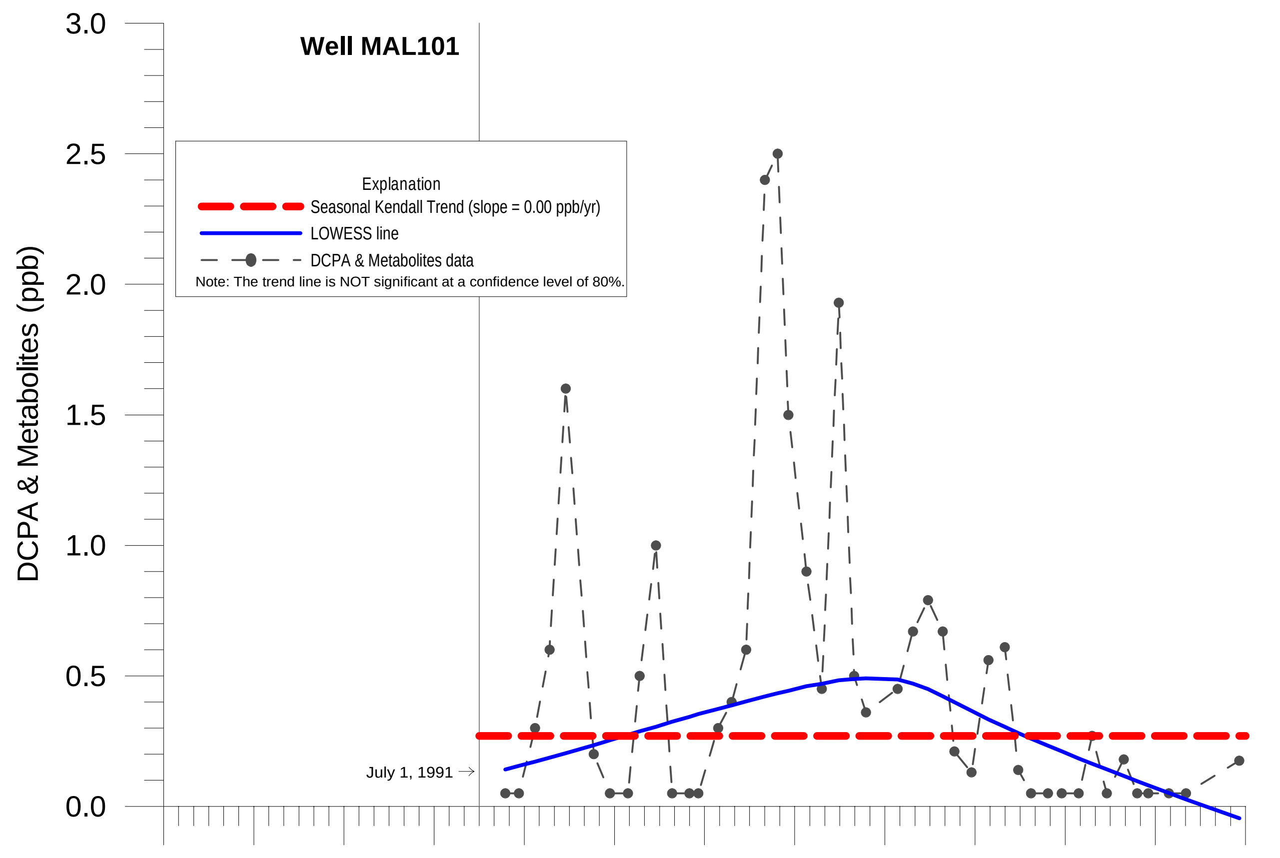

Well MAL079
Nitrate (ppm)
Explanation
Seasonal Kendall Trend (slope = -0.54 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
0
5
10
15
20
25
30
35
40
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

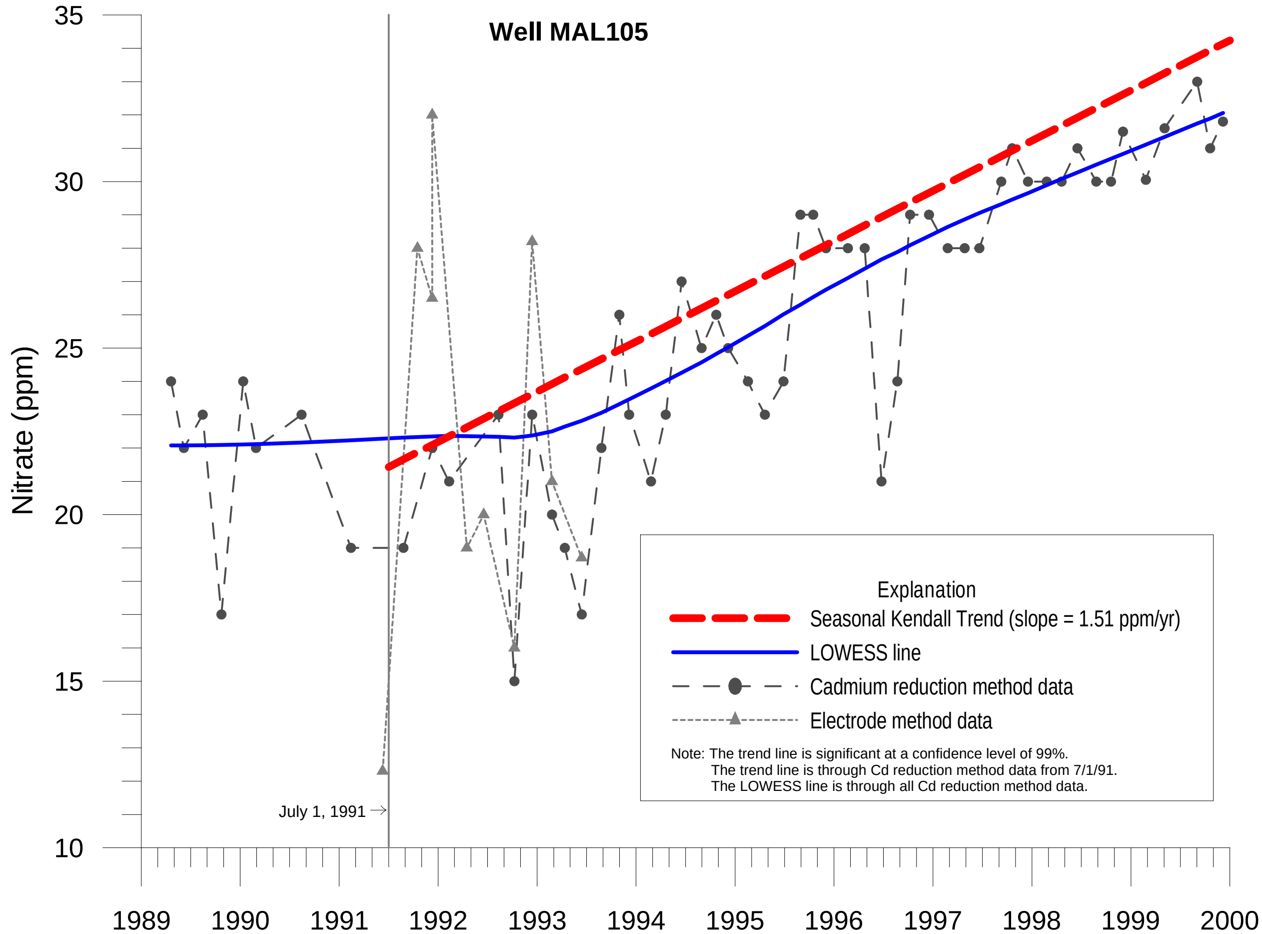

Well MAL079
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = -1.13 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
July 1, 1991
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

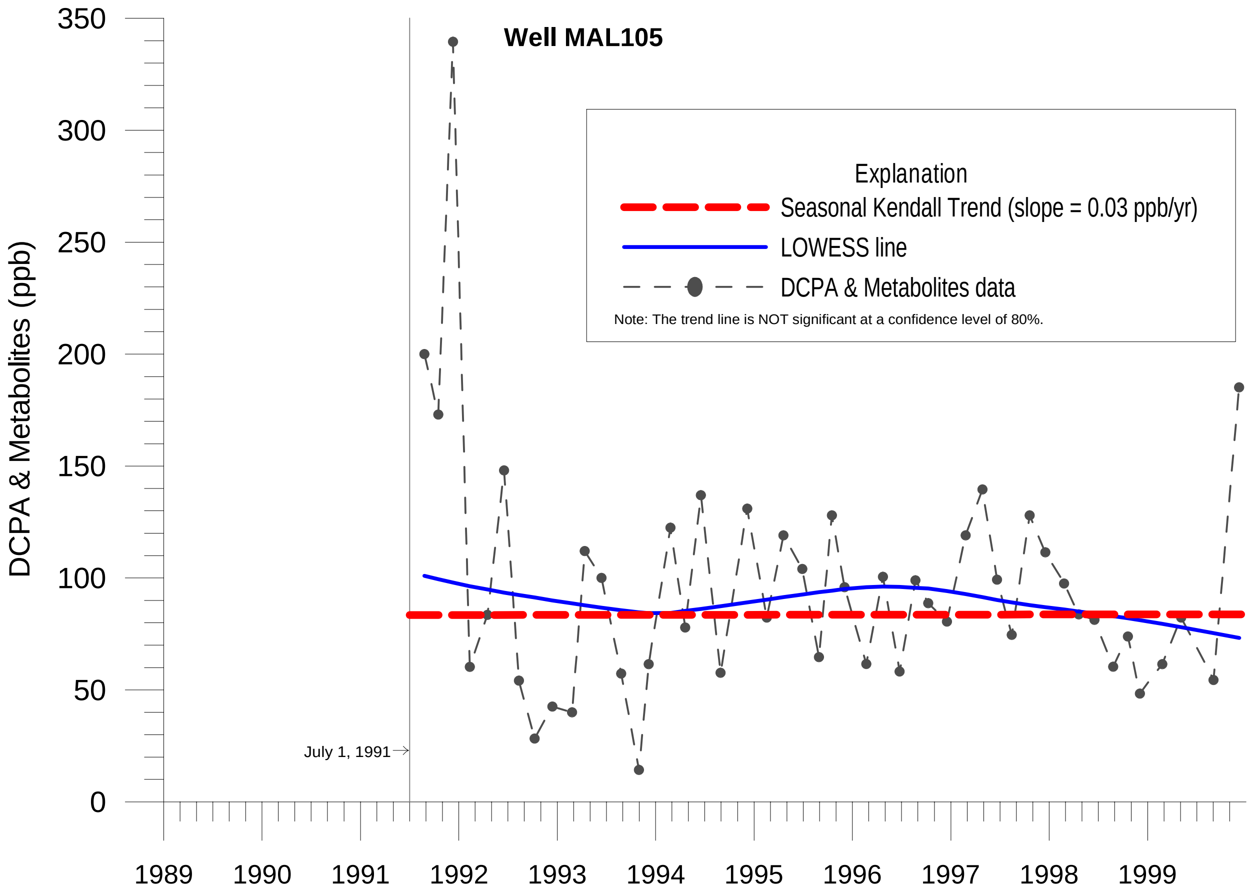

Well MAL083
Nitrate (ppm)
Explanation
Seasonal Kendall Trend (slope = -3.30 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991 →
5
10
15
20
25
30
35
40
45
50
55
60
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

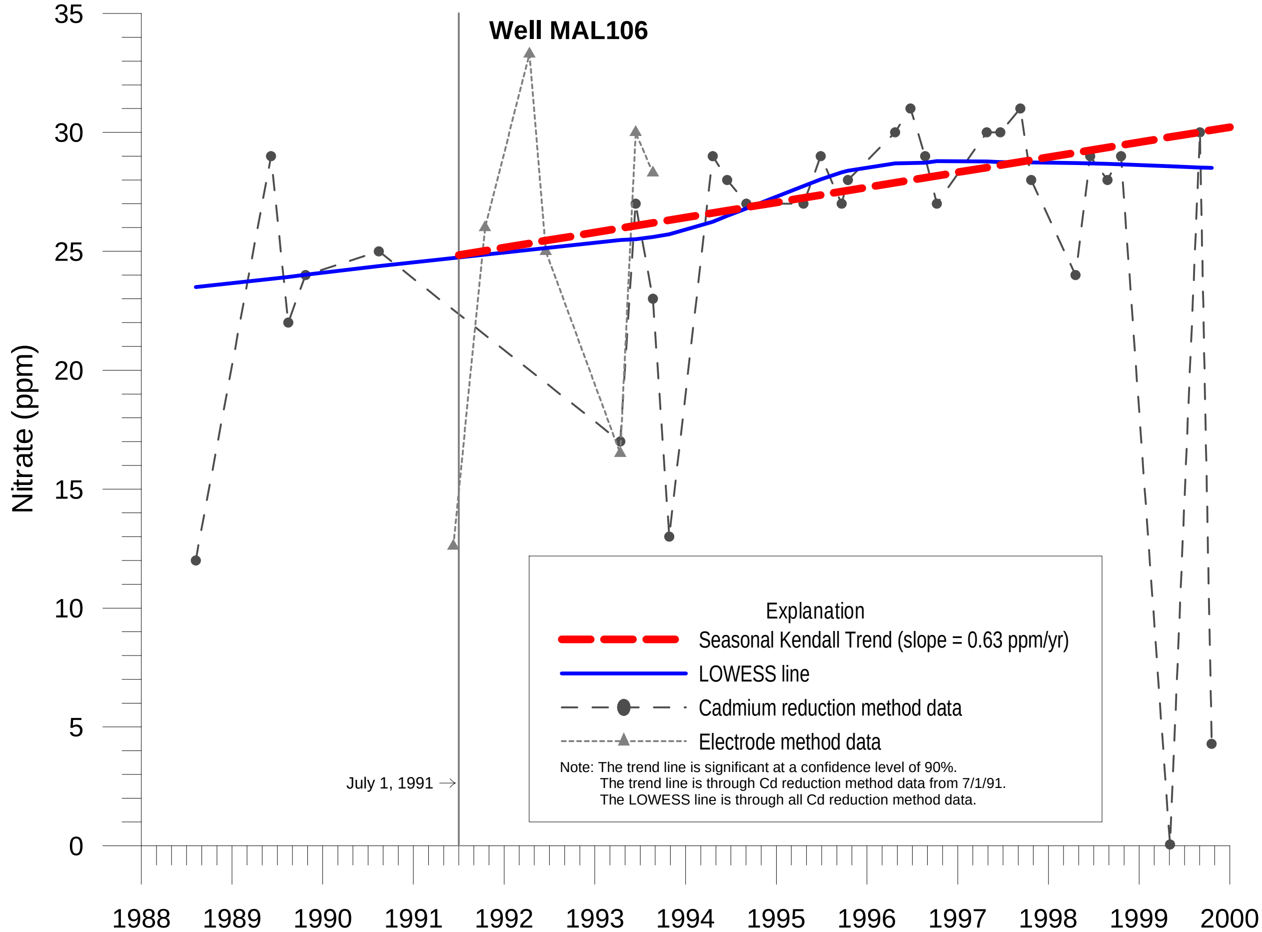

Well MAL083
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = -15.79 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
July 1, 1991 →
0
20
40
60
80
100
120
140
160
180
200
220
240
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

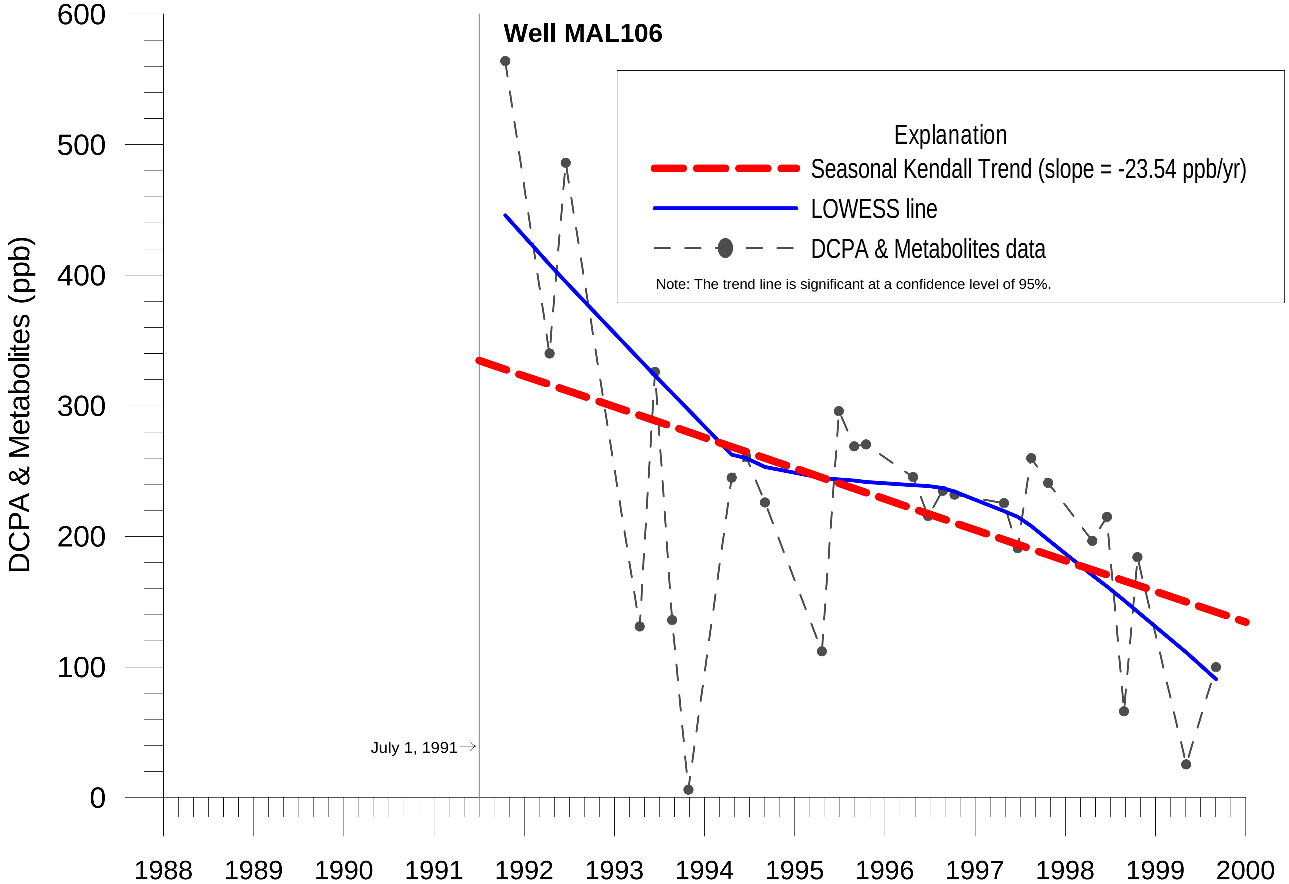

Well MAL101
Explanation
Seasonal Kendall Trend (slope = -0.62 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
Nitrate (ppm)
0
5
10
15
20
25
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

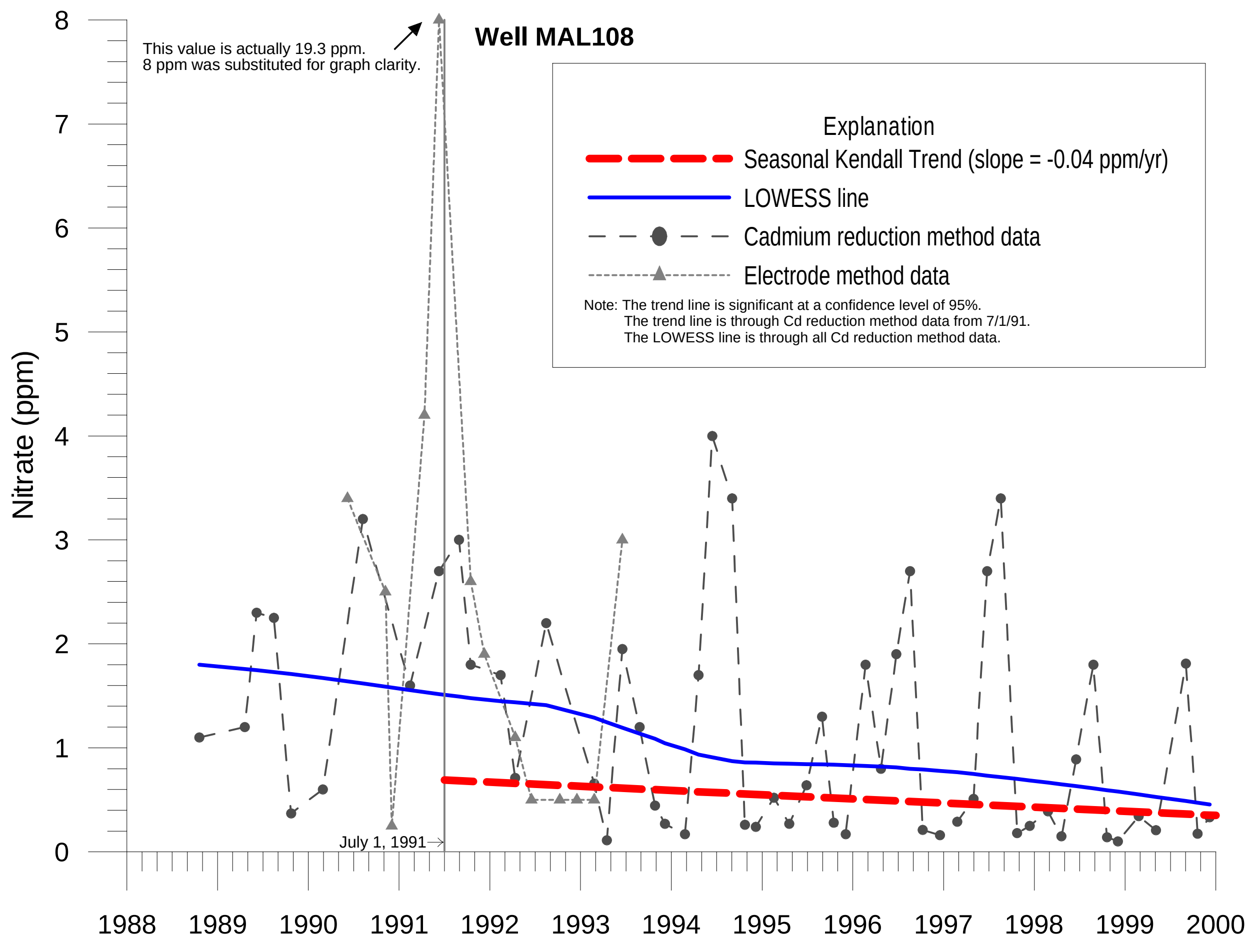

Well MAL101
Explanation
Seasonal Kendall Trend (slope = 0.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
July 1, 1991
DCPA & Metabolites (ppb)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

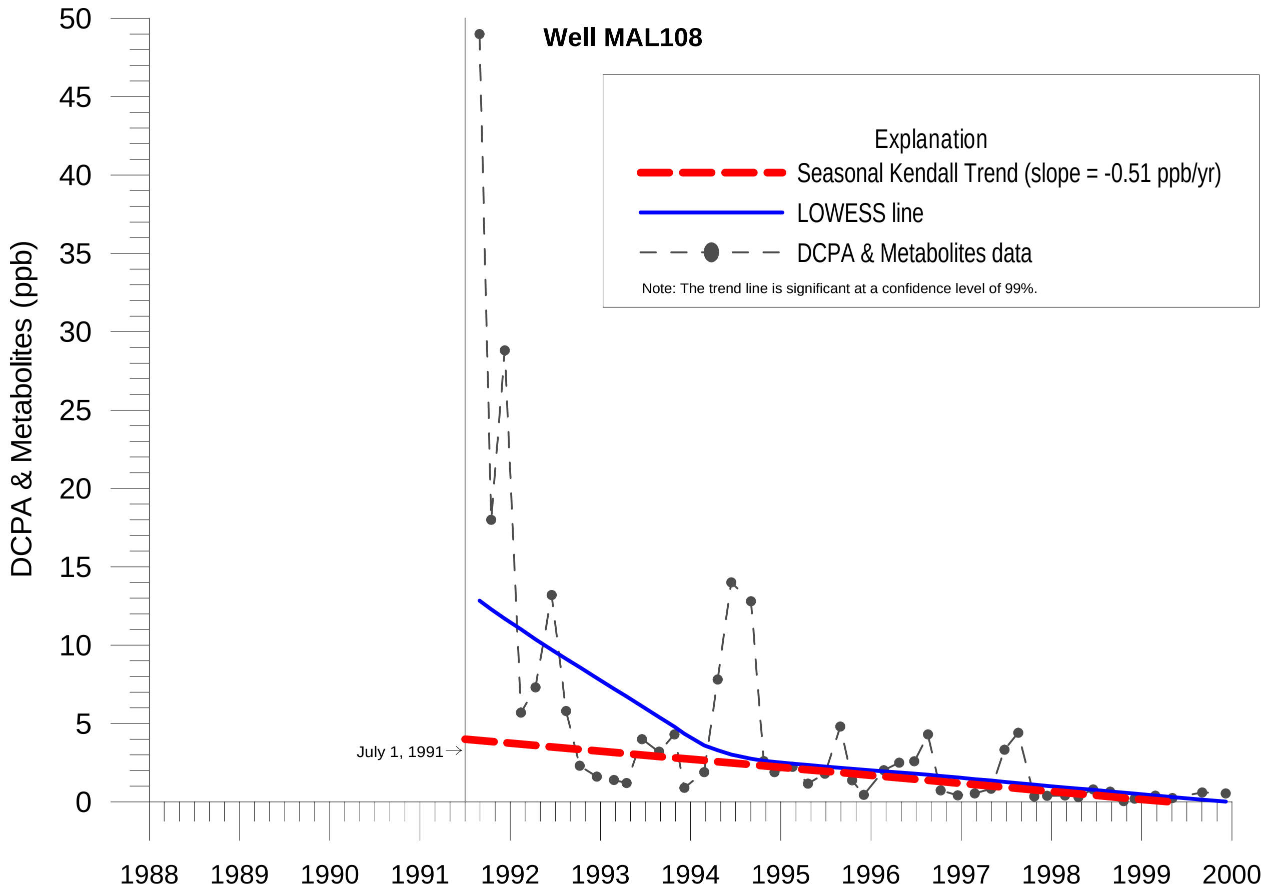

Well MAL105
Nitrate (ppm)
35
30
25
20
15
10
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 1.51 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

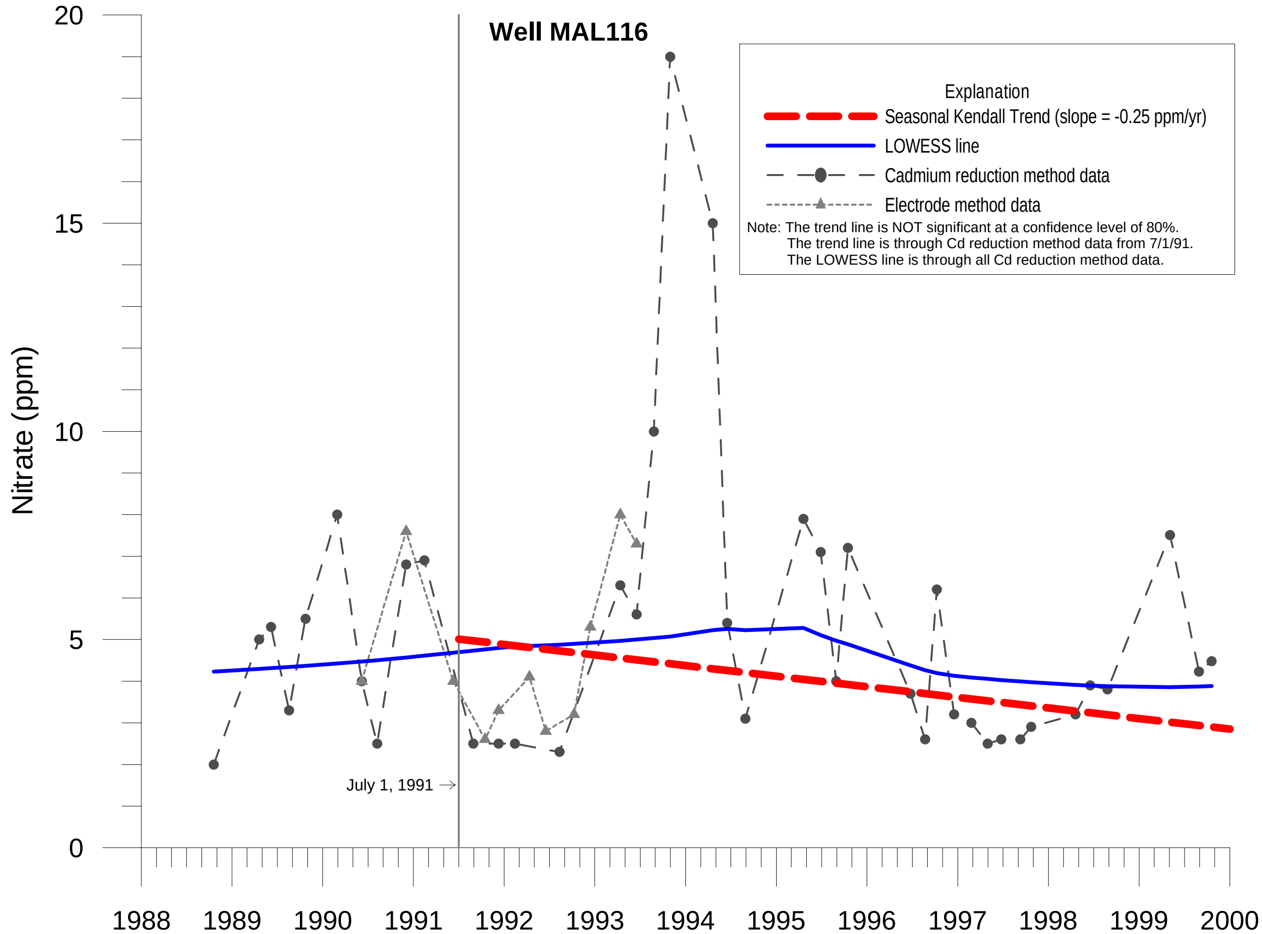

Well MAL105
DCPA & Metabolites (ppb)
350
300
250
200
150
100
50
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 0.03 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.

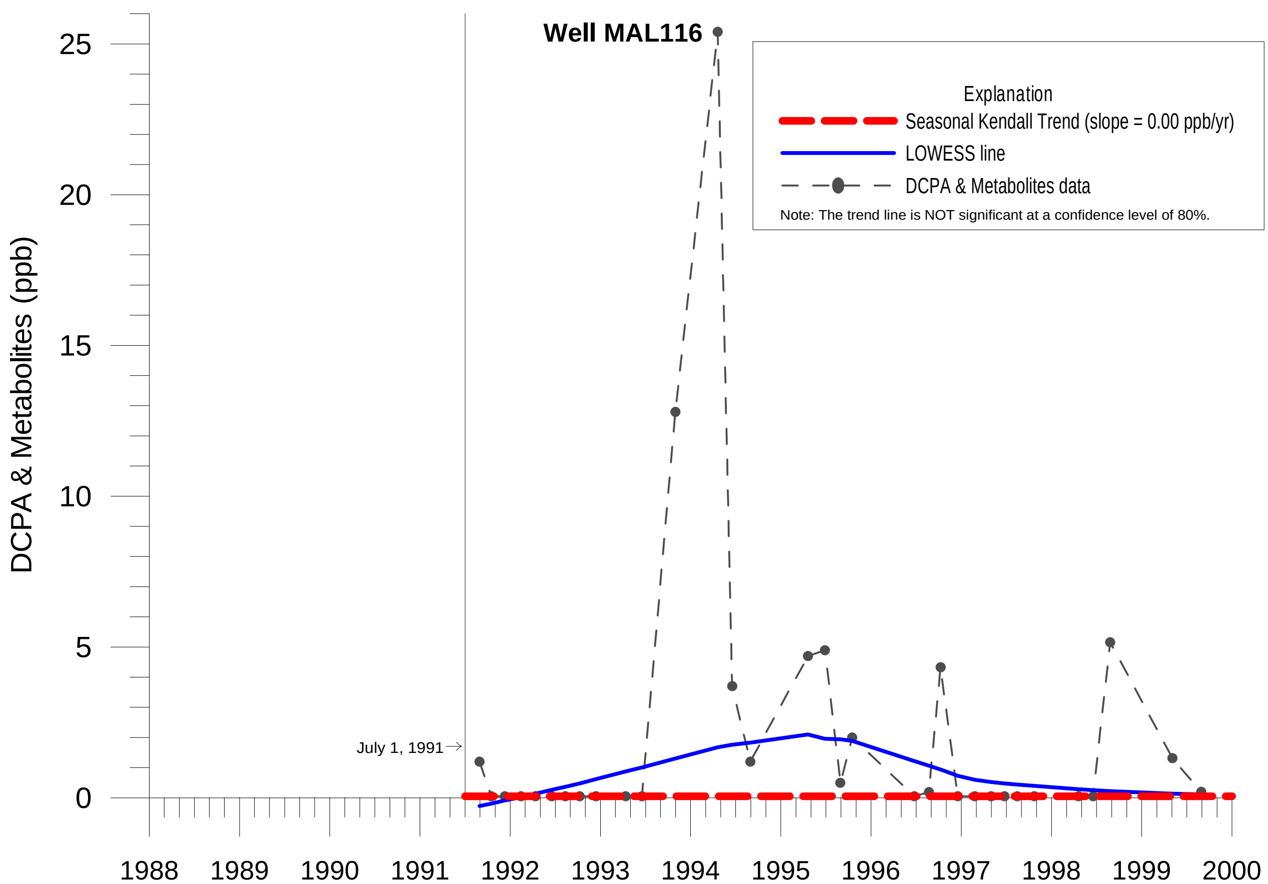

Well MAL106
Nitrate (ppm)
35
30
25
20
15
10
5
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 0.63 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 90%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

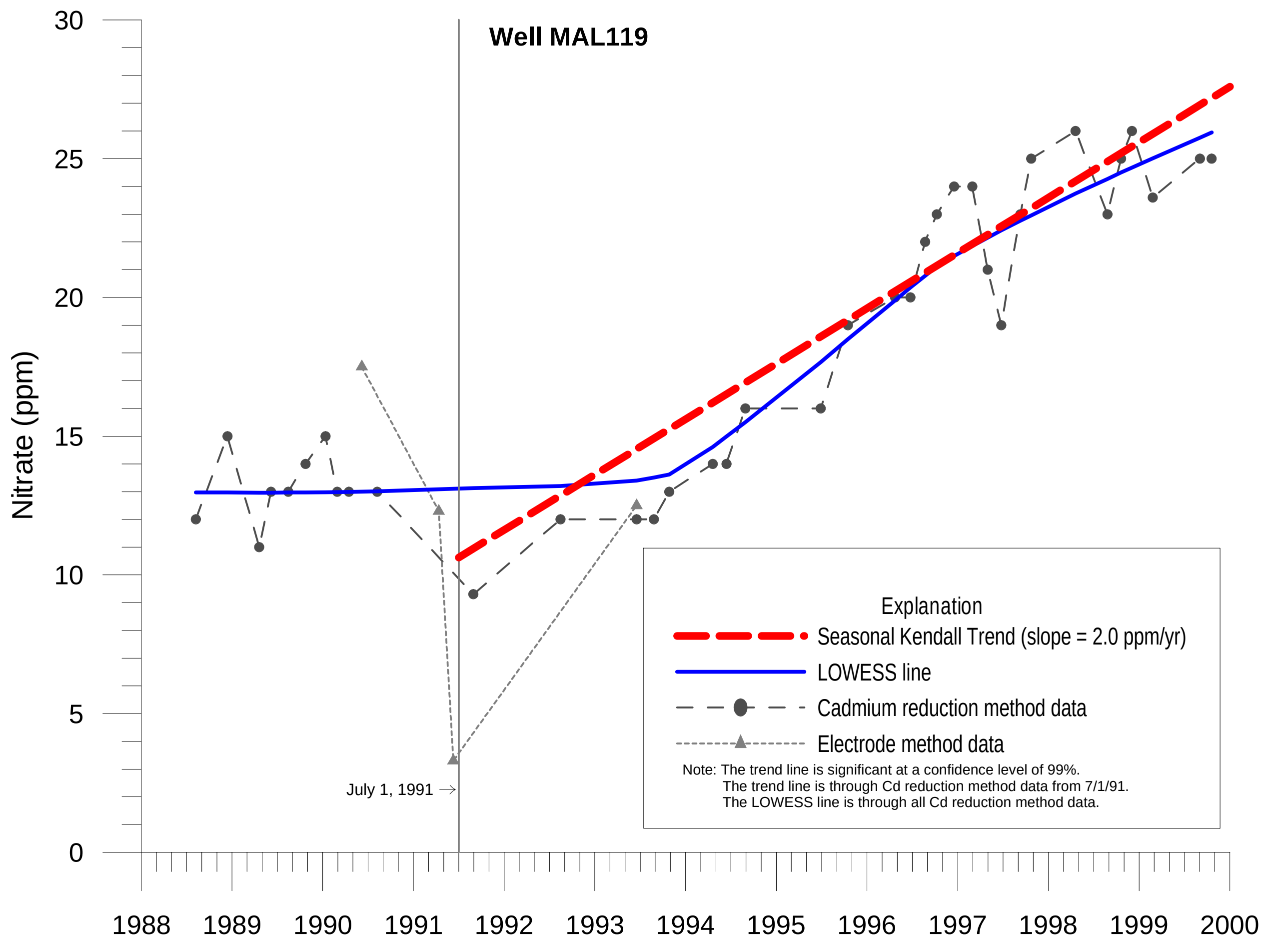

Well MAL106
DCPA & Metabolites (ppb)
600
500
400
300
200
100
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = -23.54 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 95%.

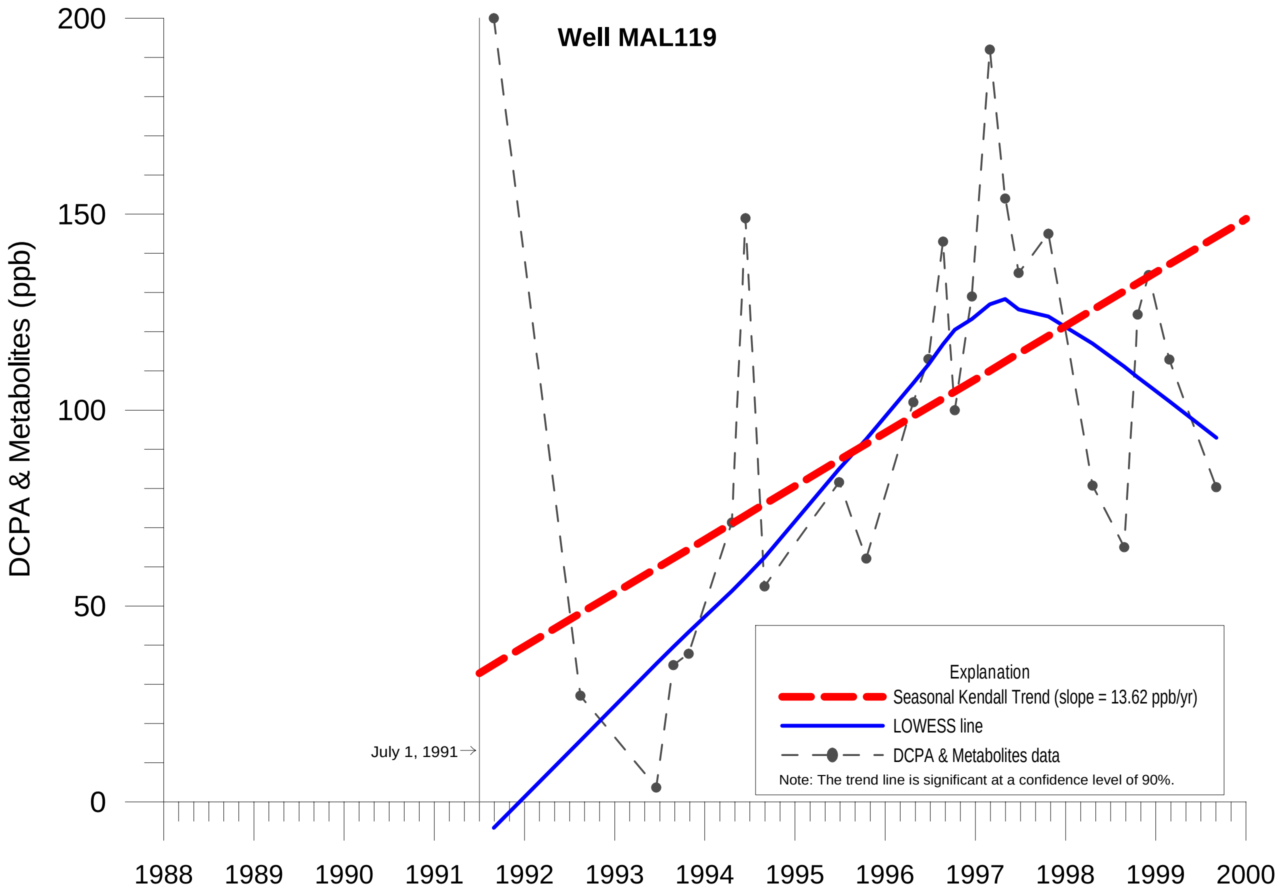

Well MAL108
This value is actually 19.3 ppm.
8 ppm was substituted for graph clarity.
Explanation
Seasonal Kendall Trend (slope = -0.04 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 95%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
Nitrate (ppm)
0
1
2
3
4
5
6
7
8
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

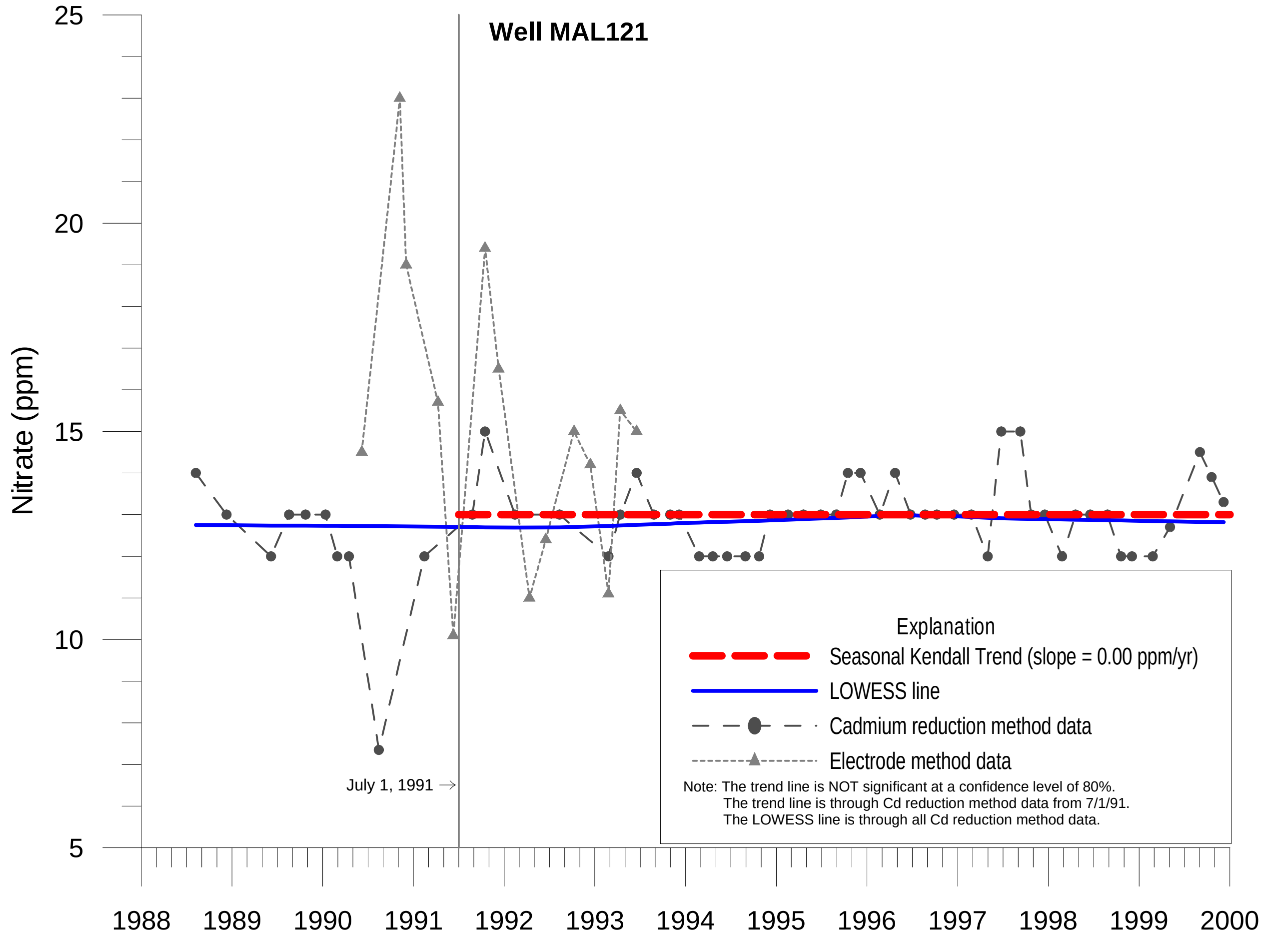

Well MAL108
Explanation
Seasonal Kendall Trend (slope = -0.51 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
July 1, 1991
DCPA & Metabolites (ppb)
0
5
10
15
20
25
30
35
40
45
50
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

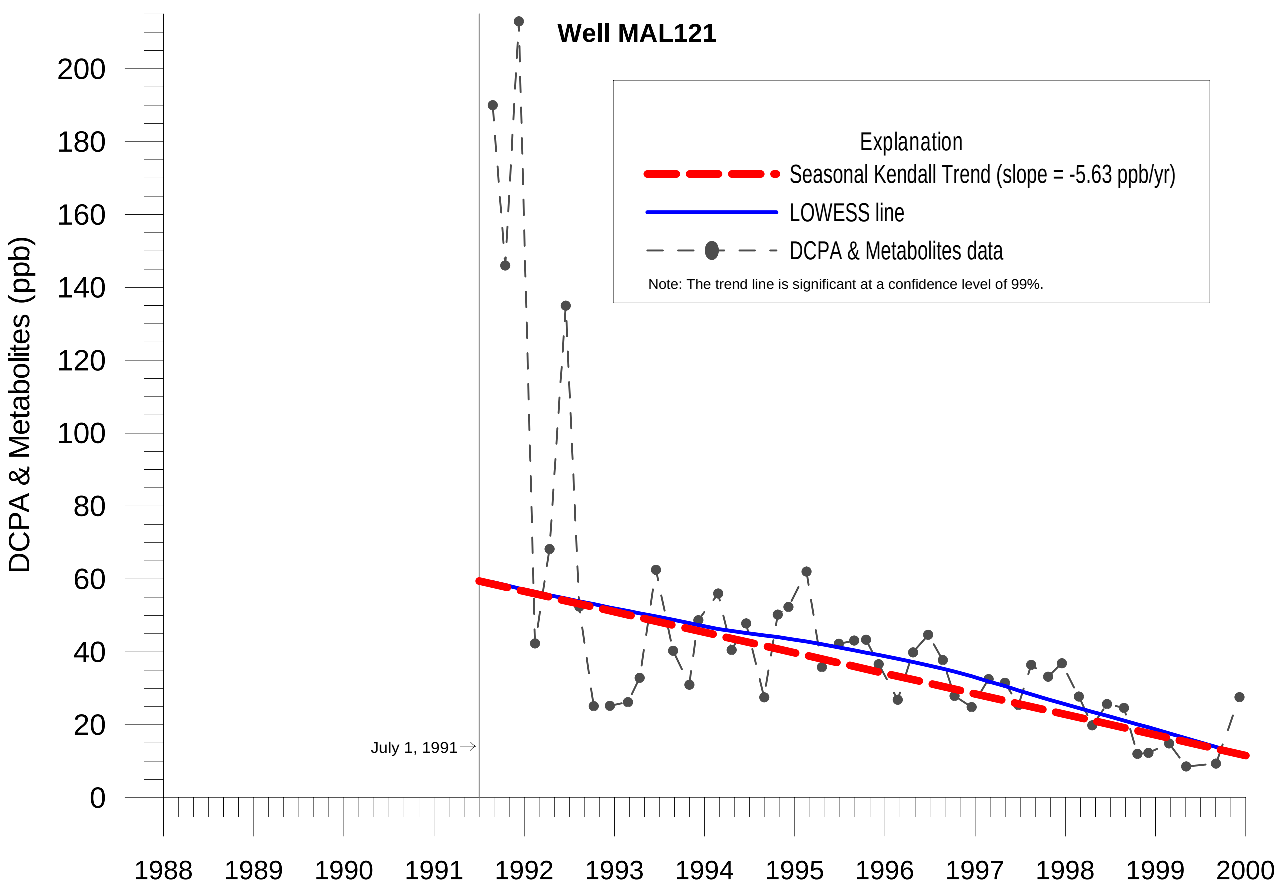

Well MAL116
Nitrate (ppm)
20
15
10
5
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = -0.25 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

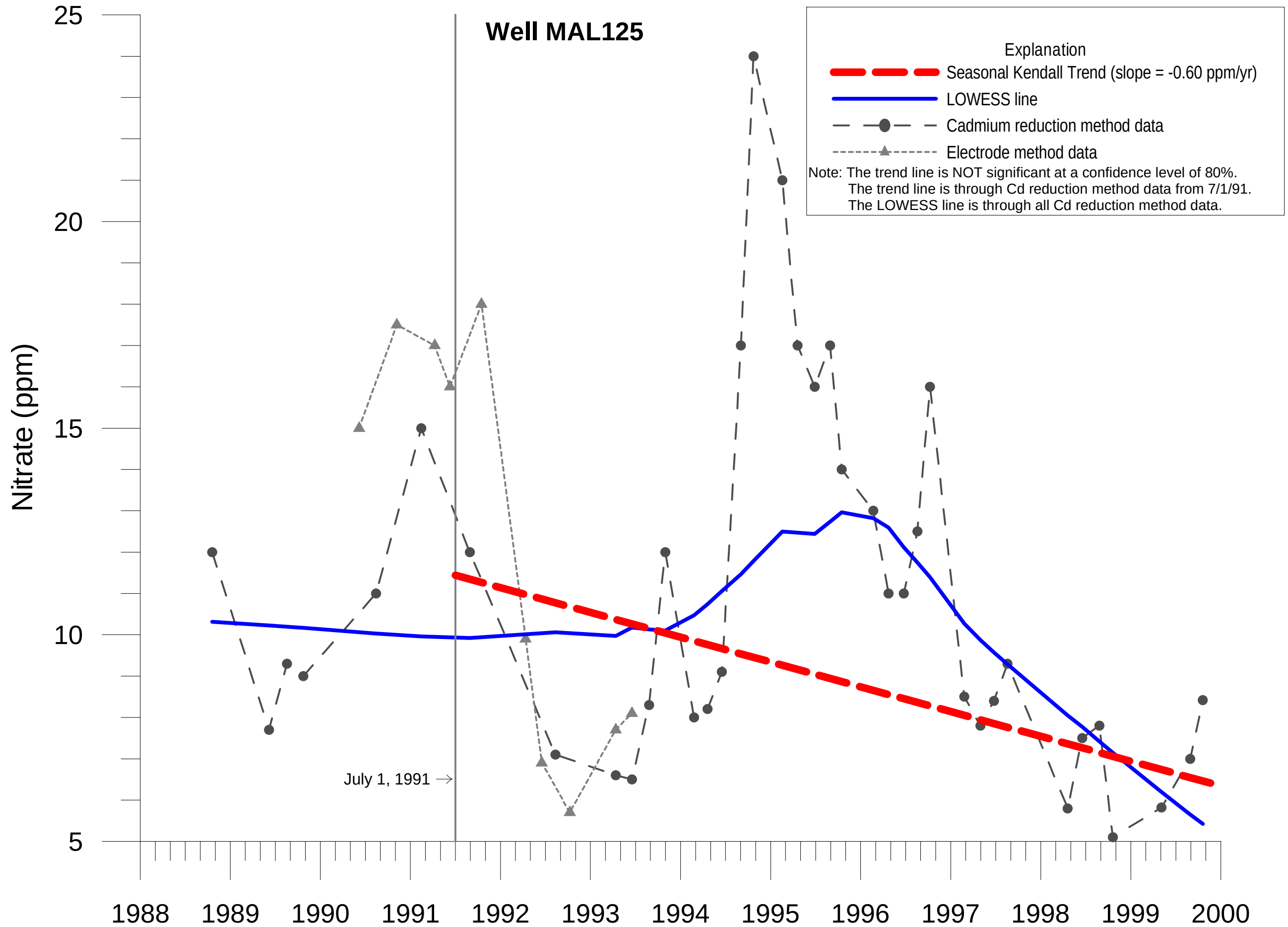

Well MAL116
DCPA & Metabolites (ppb)
25
20
15
10
5
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 0.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.

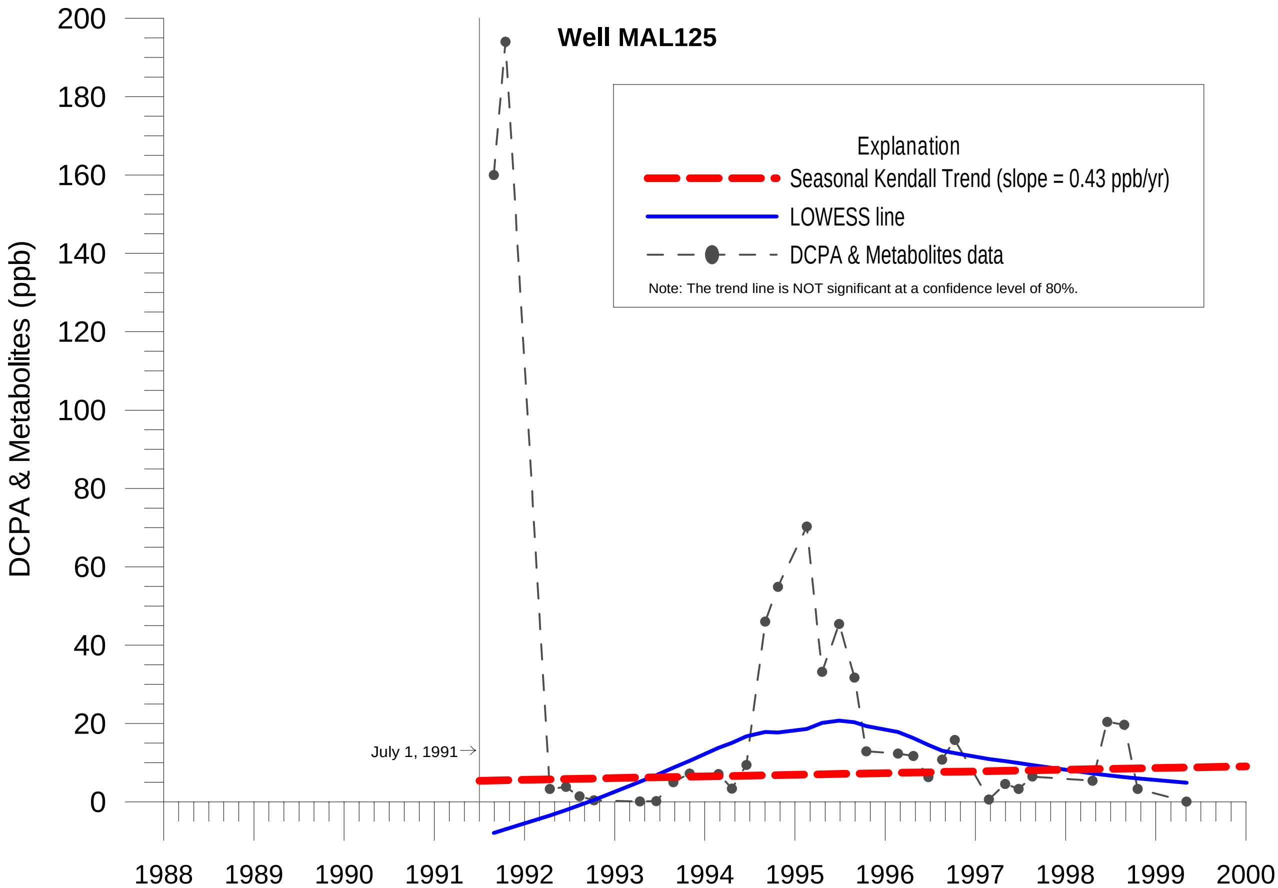

Well MAL119
Nitrate (ppm)
30
25
20
15
10
5
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 2.0 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

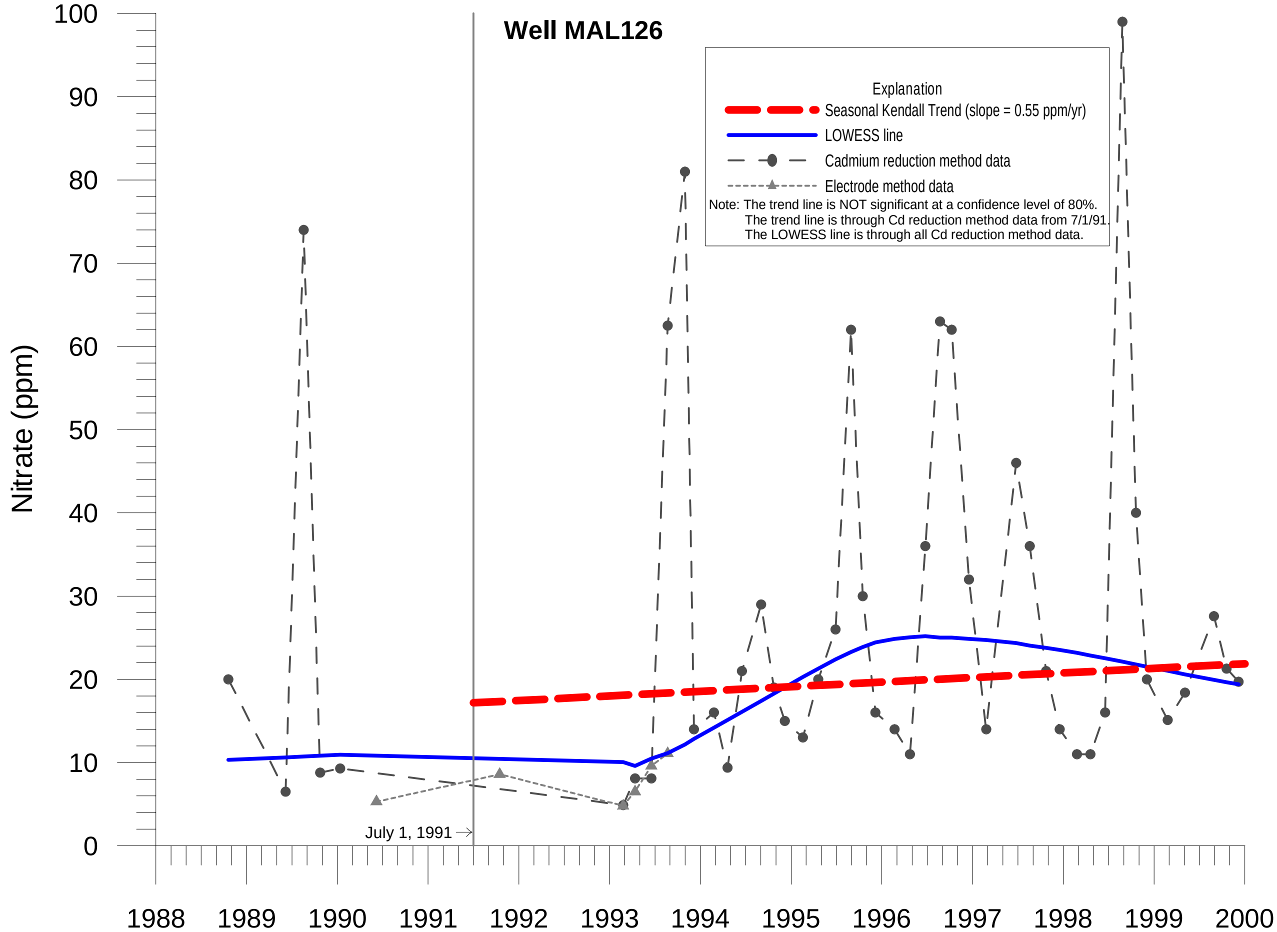

Well MAL119
DCPA & Metabolites (ppb)
200
150
100
50
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 13.62 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 90%.

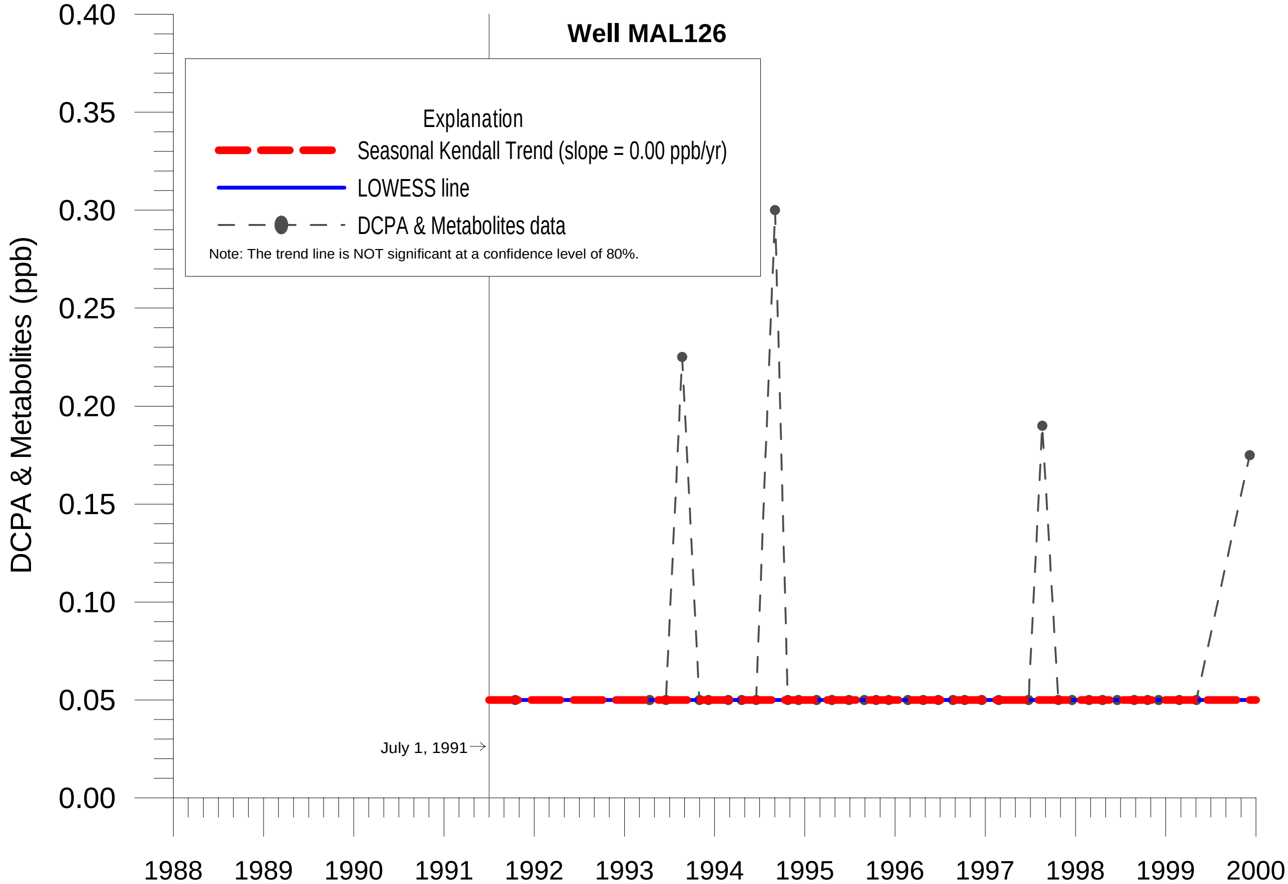

Well MAL121
Nitrate (ppm)
25
20
15
10
5
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 0.00 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

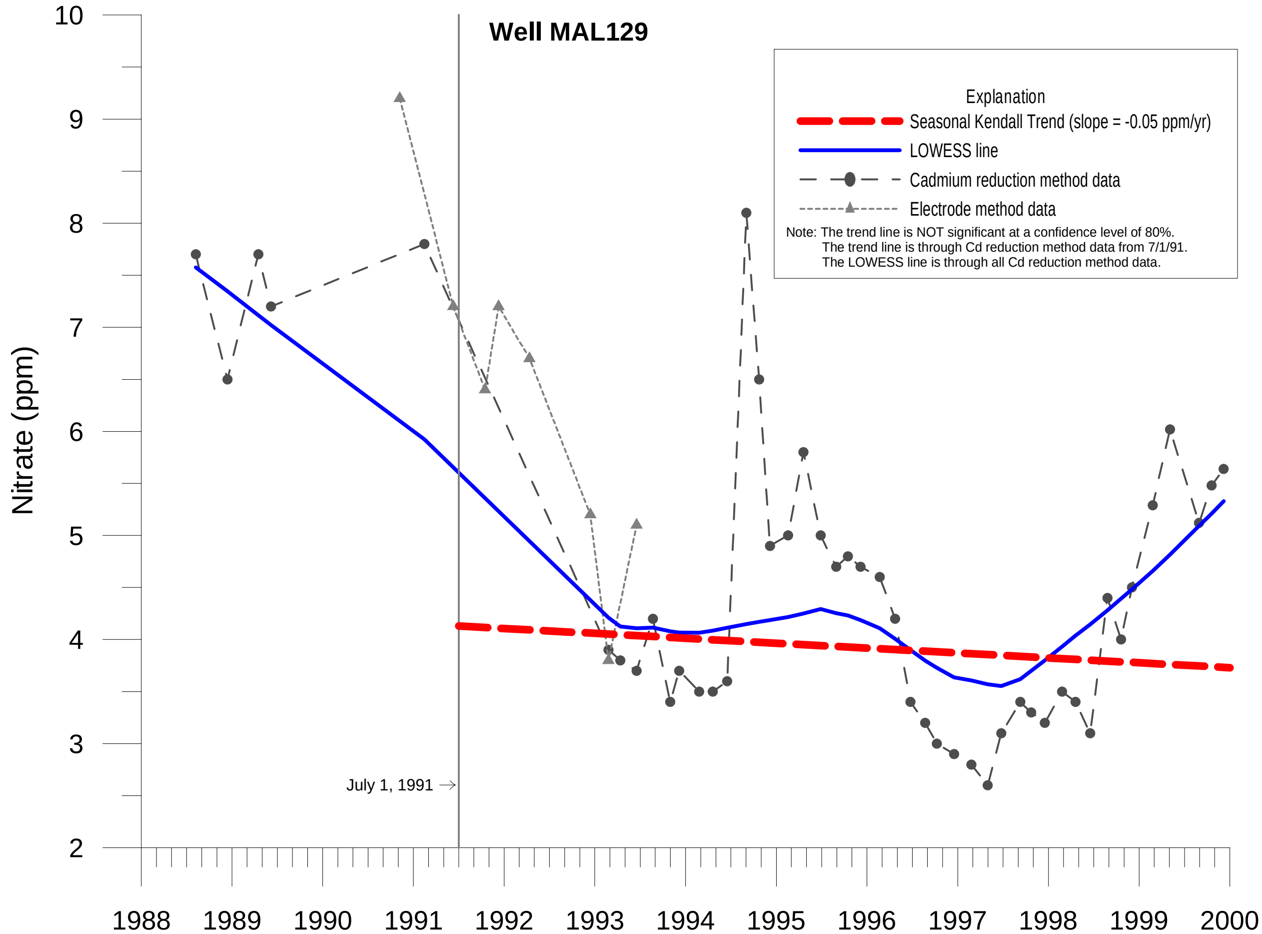

Well MAL121
DCPA & Metabolites (ppb)
200
180
160
140
120
100
80
60
40
20
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = -5.63 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.

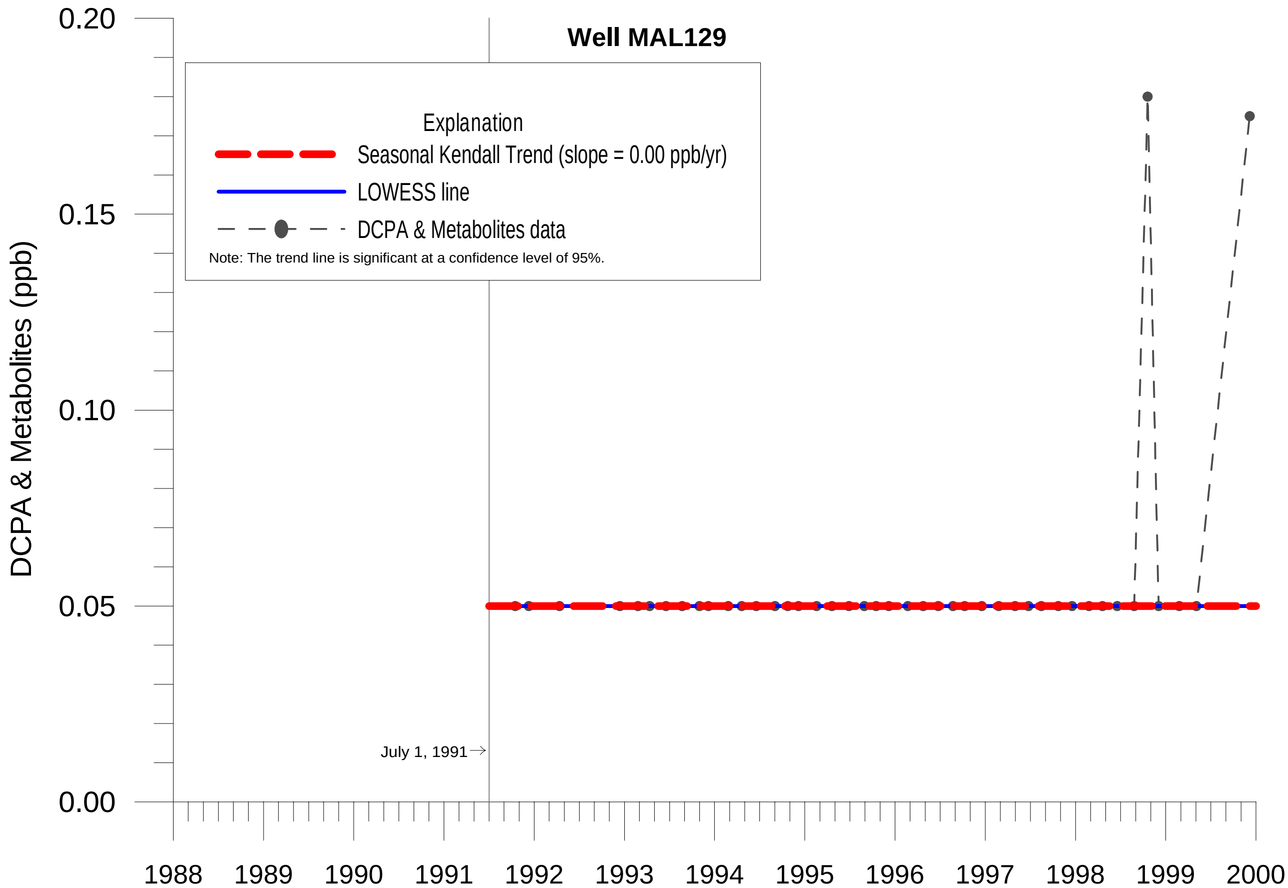

Well MAL125
Explanation
Seasonal Kendall Trend (slope = -0.60 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
25
20
15
10
5
July 1, 1991
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

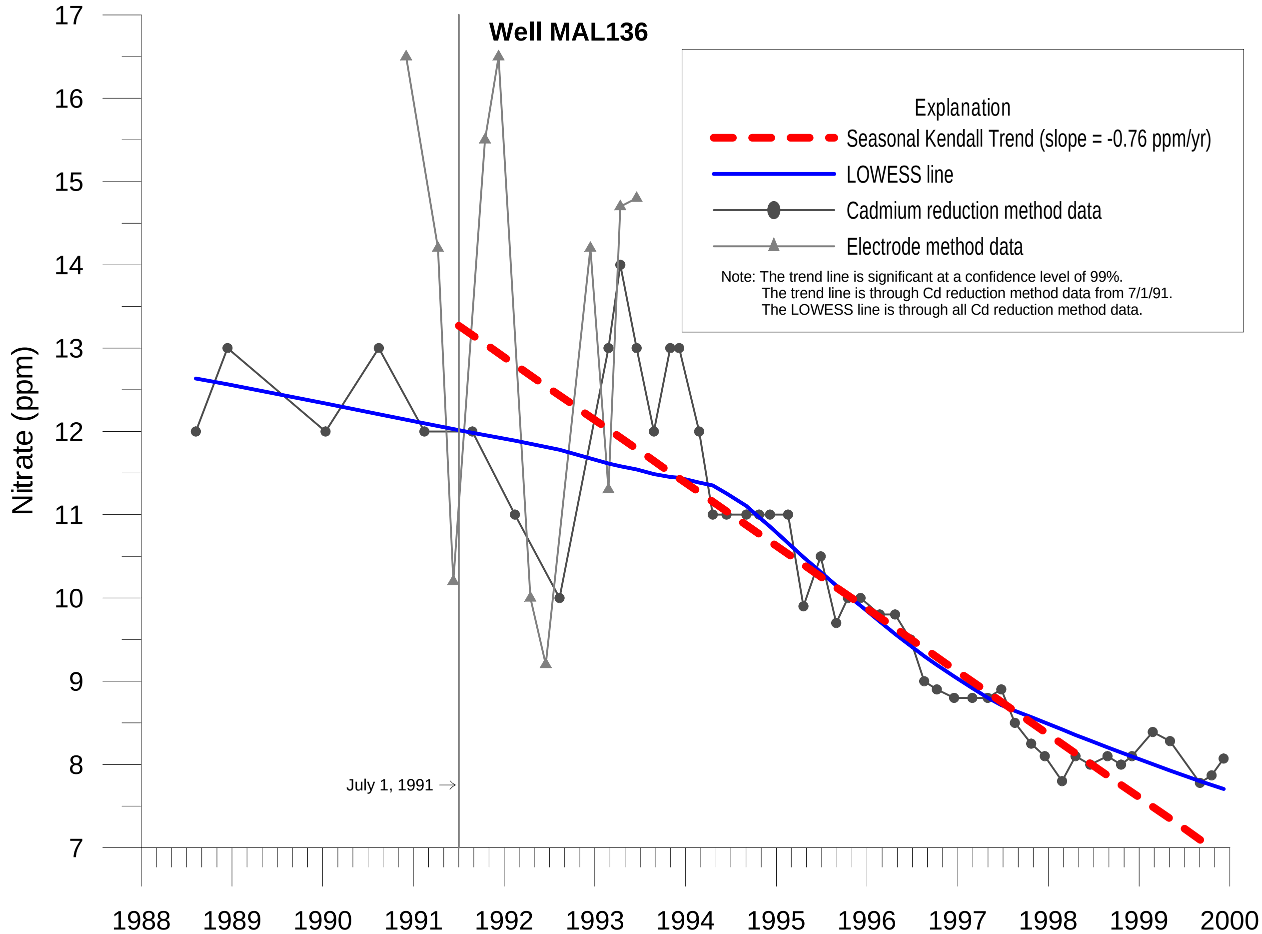

Well MAL125
Explanation
Seasonal Kendall Trend (slope = 0.43 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
200
180
160
140
120
100
80
60
40
20
0
July 1, 1991
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

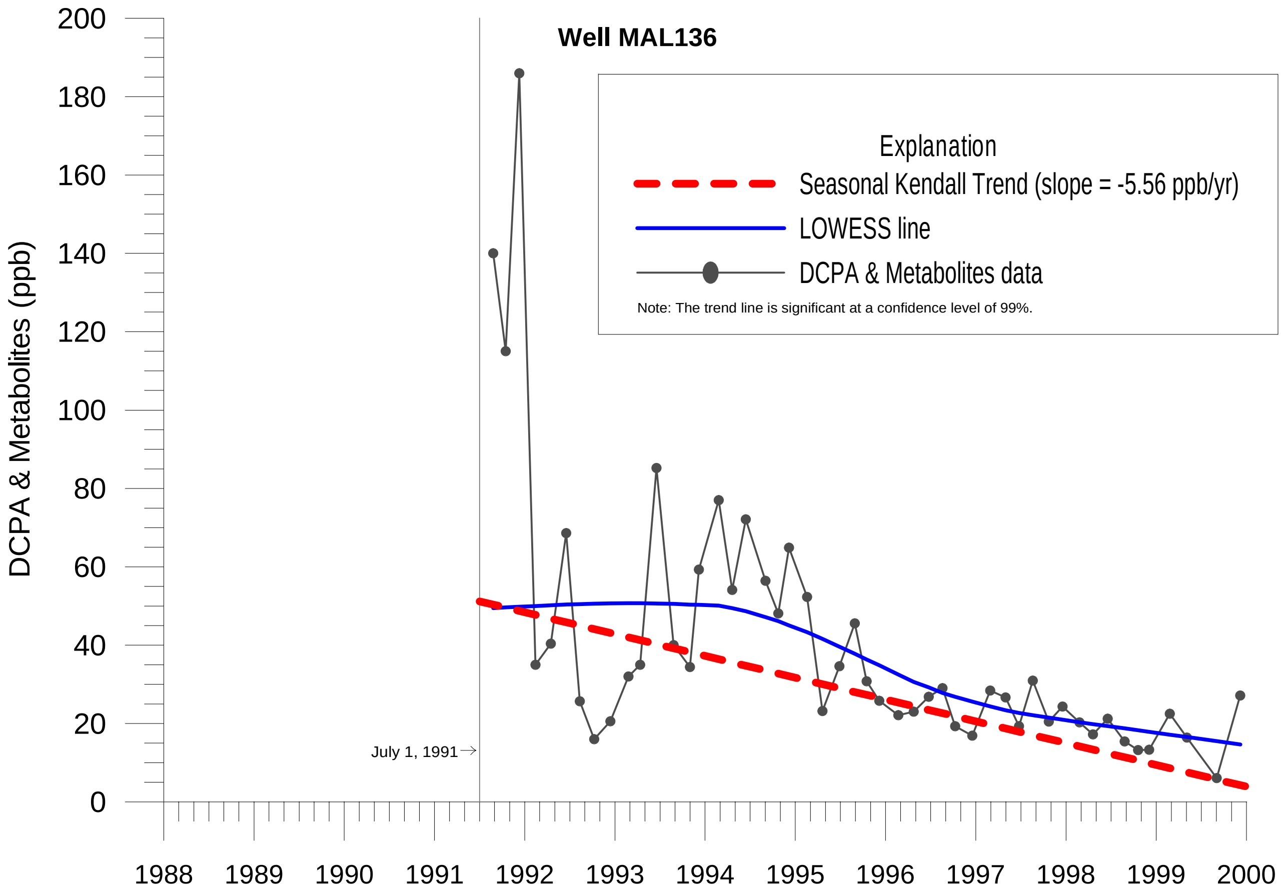

Well MAL126
Explanation
Seasonal Kendall Trend (slope = 0.55 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
0
10
20
30
40
50
60
70
80
90
100
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

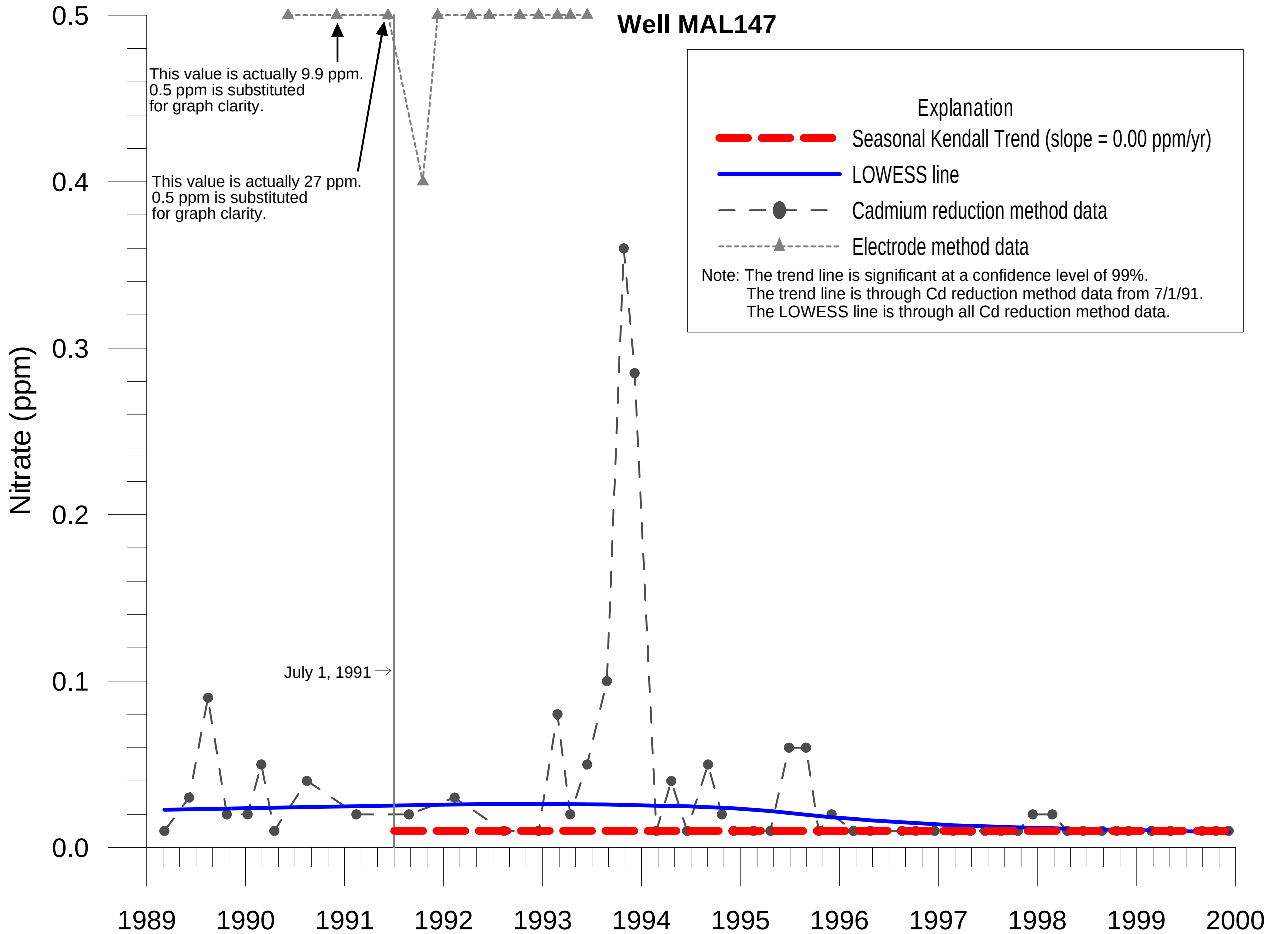

Well MAL126
Explanation
Seasonal Kendall Trend (slope = 0.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Well MAL129
Explanation
Seasonal Kendall Trend (slope = -0.05 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
10
9
8
7
6
5
4
3
2
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

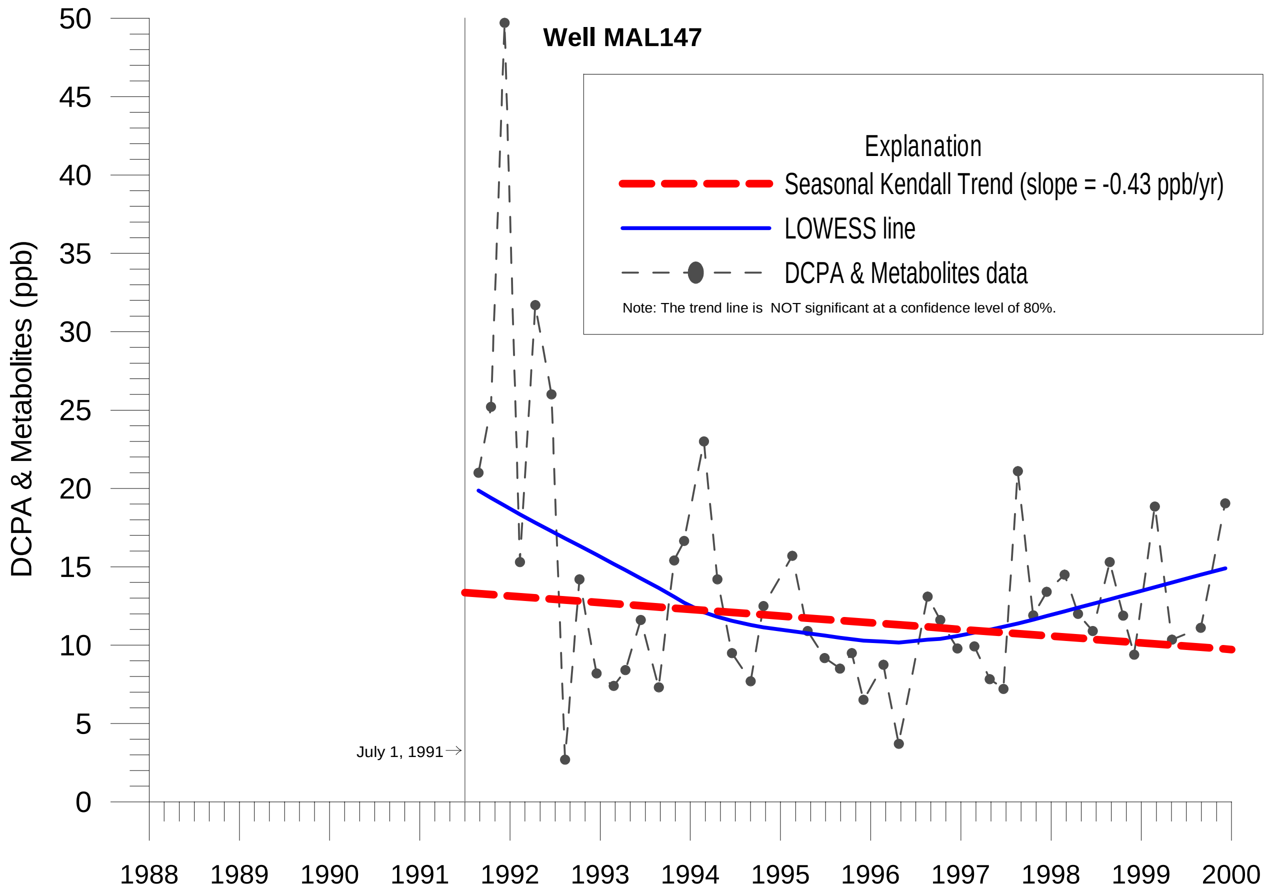

Well MAL129
Explanation
Seasonal Kendall Trend (slope = 0.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 95%.
DCPA & Metabolites (ppb)
July 1, 1991
0.20
0.15
0.10
0.05
0.00
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Well MAL136
Explanation
Seasonal Kendall Trend (slope = -0.76 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
17
16
15
14
13
12
11
10
9
8
7
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

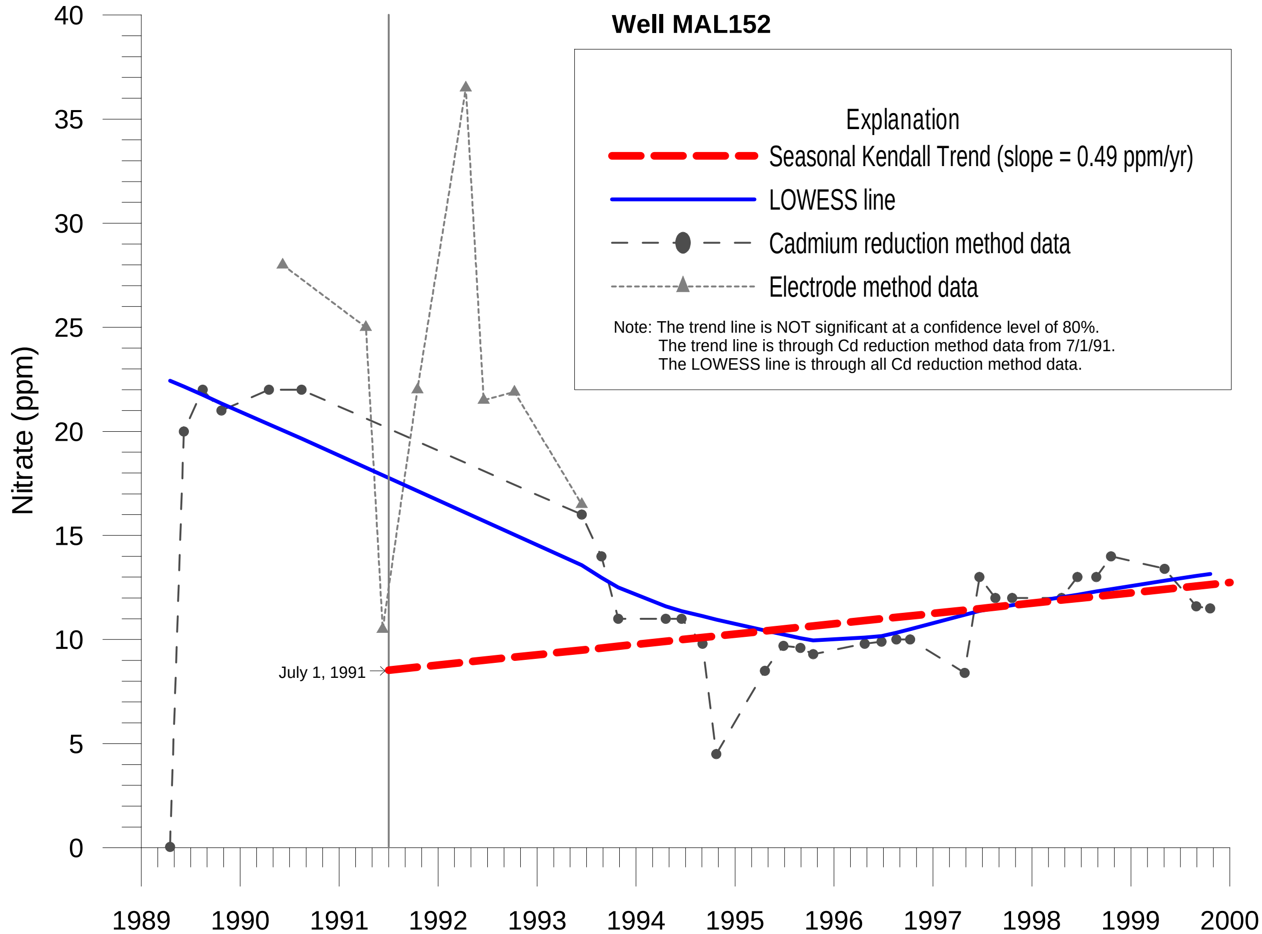

Well MAL136
Explanation
Seasonal Kendall Trend (slope = -5.56 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
DCPA & Metabolites (ppb)
July 1, 1991
200
180
160
140
120
100
80
60
40
20
0
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

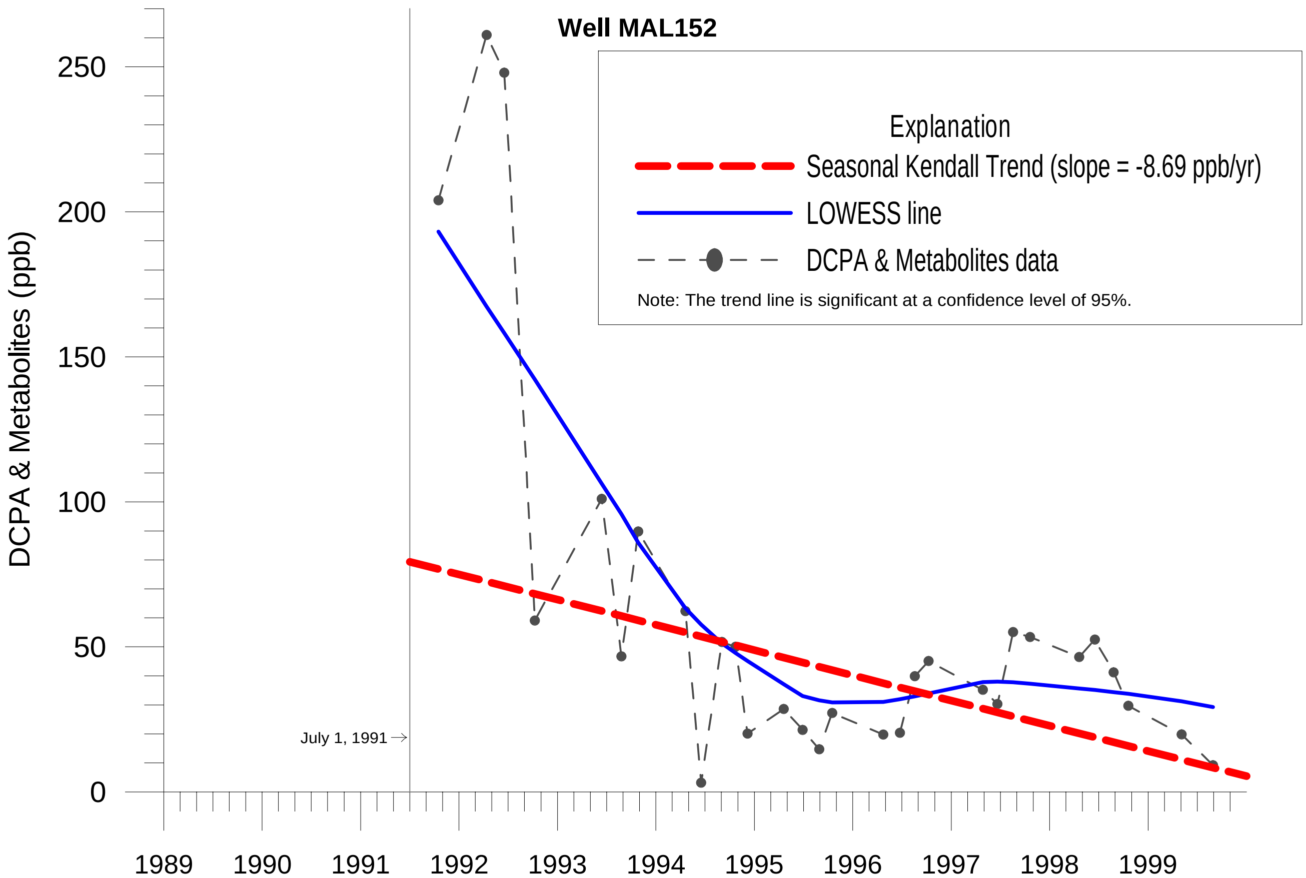


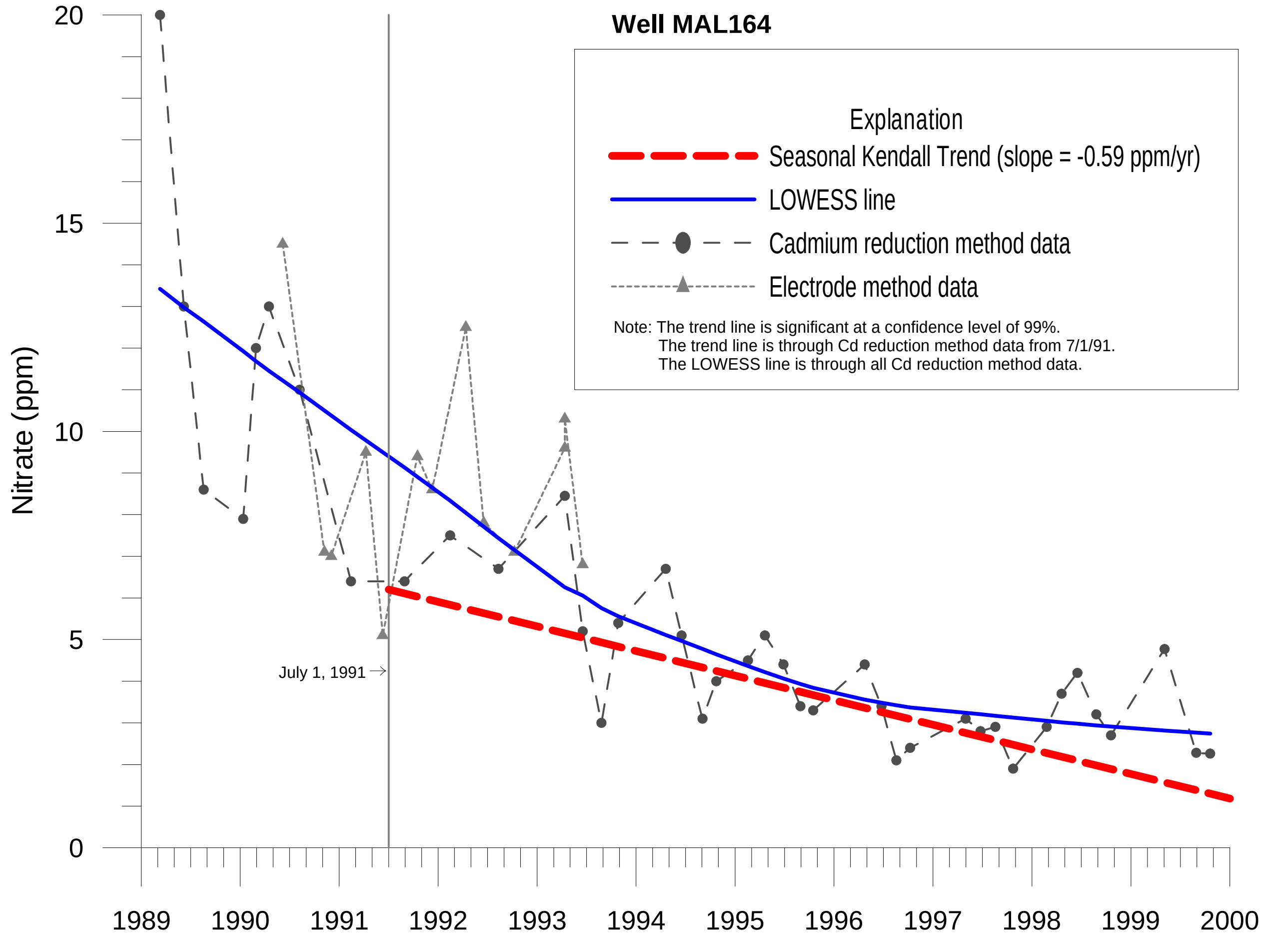
Well MAL147
Nitrate (ppm)
0.5
0.4
0.3
0.2
0.1
0.0
This value is actually 9.9 ppm. 0.5 ppm is substituted for graph clarity.
This value is actually 27 ppm. 0.5 ppm is substituted for graph clarity.
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 0.00 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

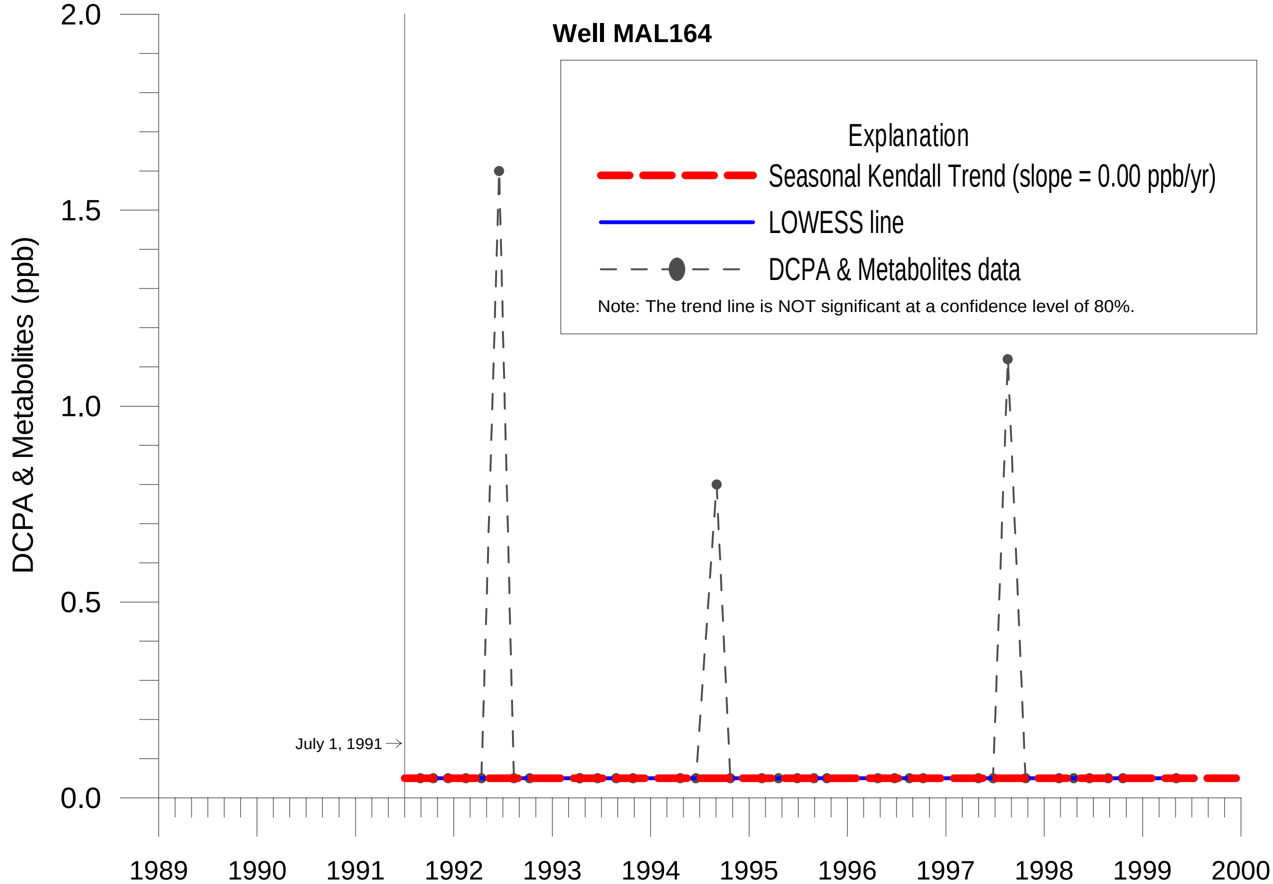


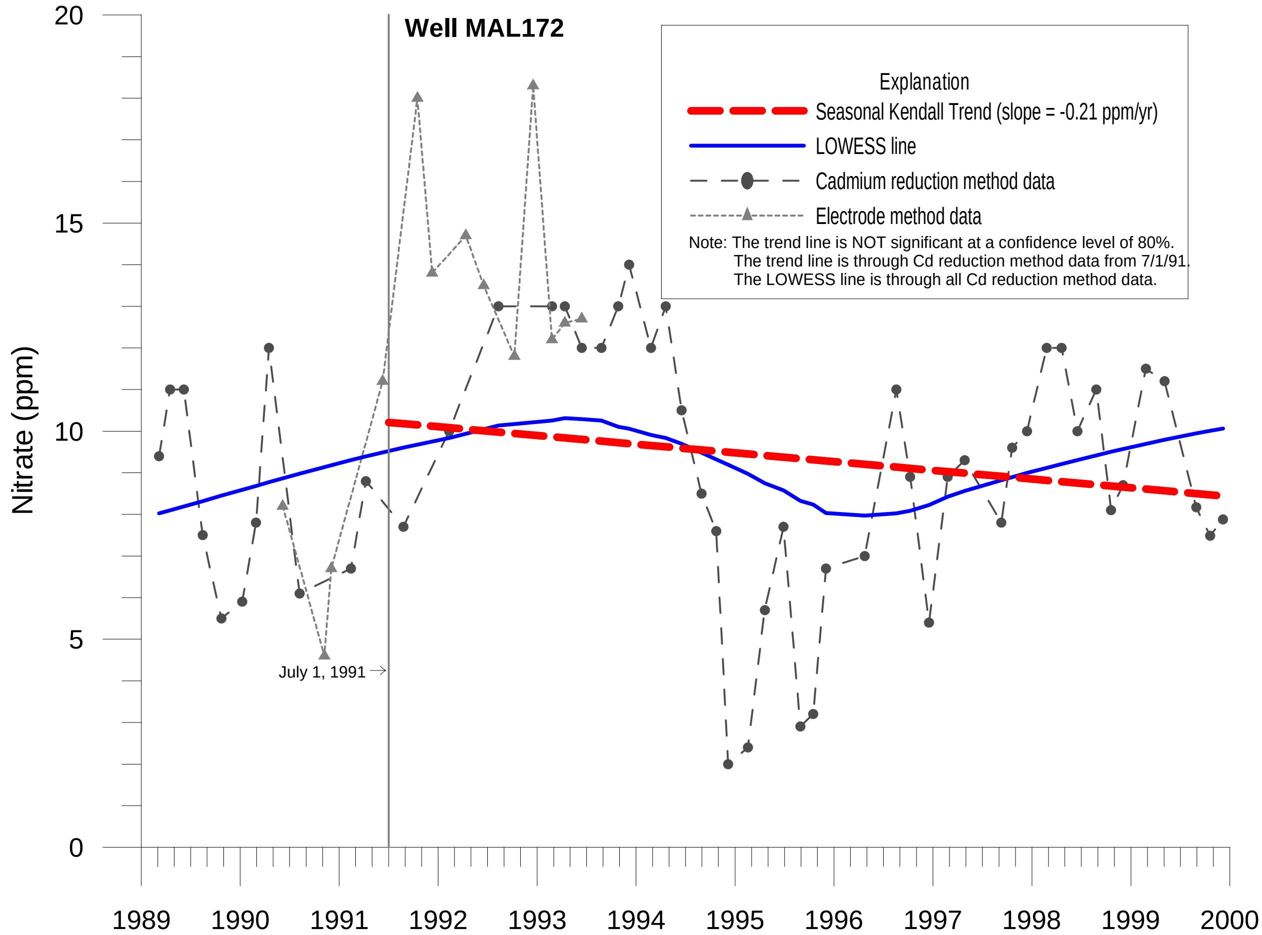
Well MAL147
DCPA & Metabolites (ppb)
50
45
40
35
30
25
20
15
10
5
0
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = -0.43 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

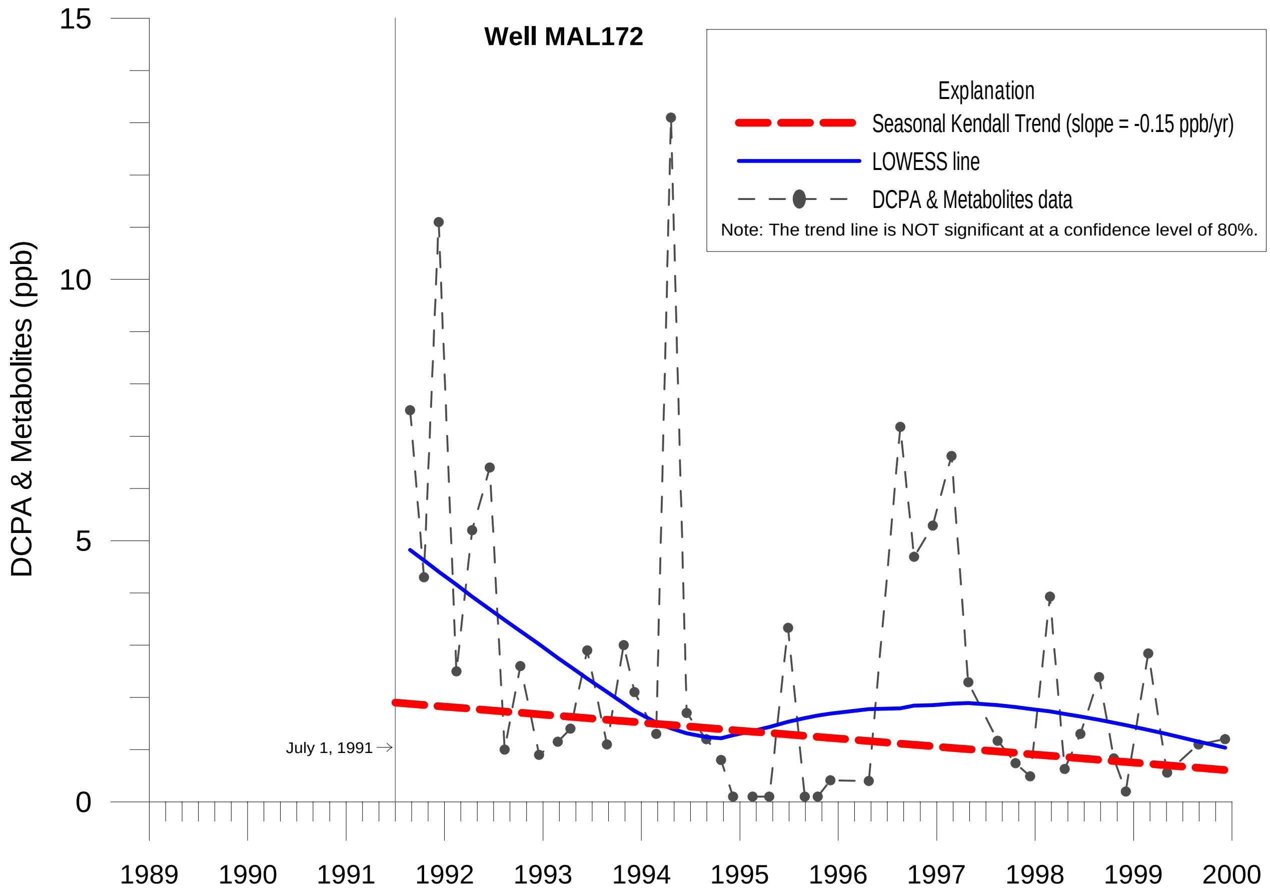

Well MAL152
Explanation
Seasonal Kendall Trend (slope = 0.49 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
0
5
10
15
20
25
30
35
40
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

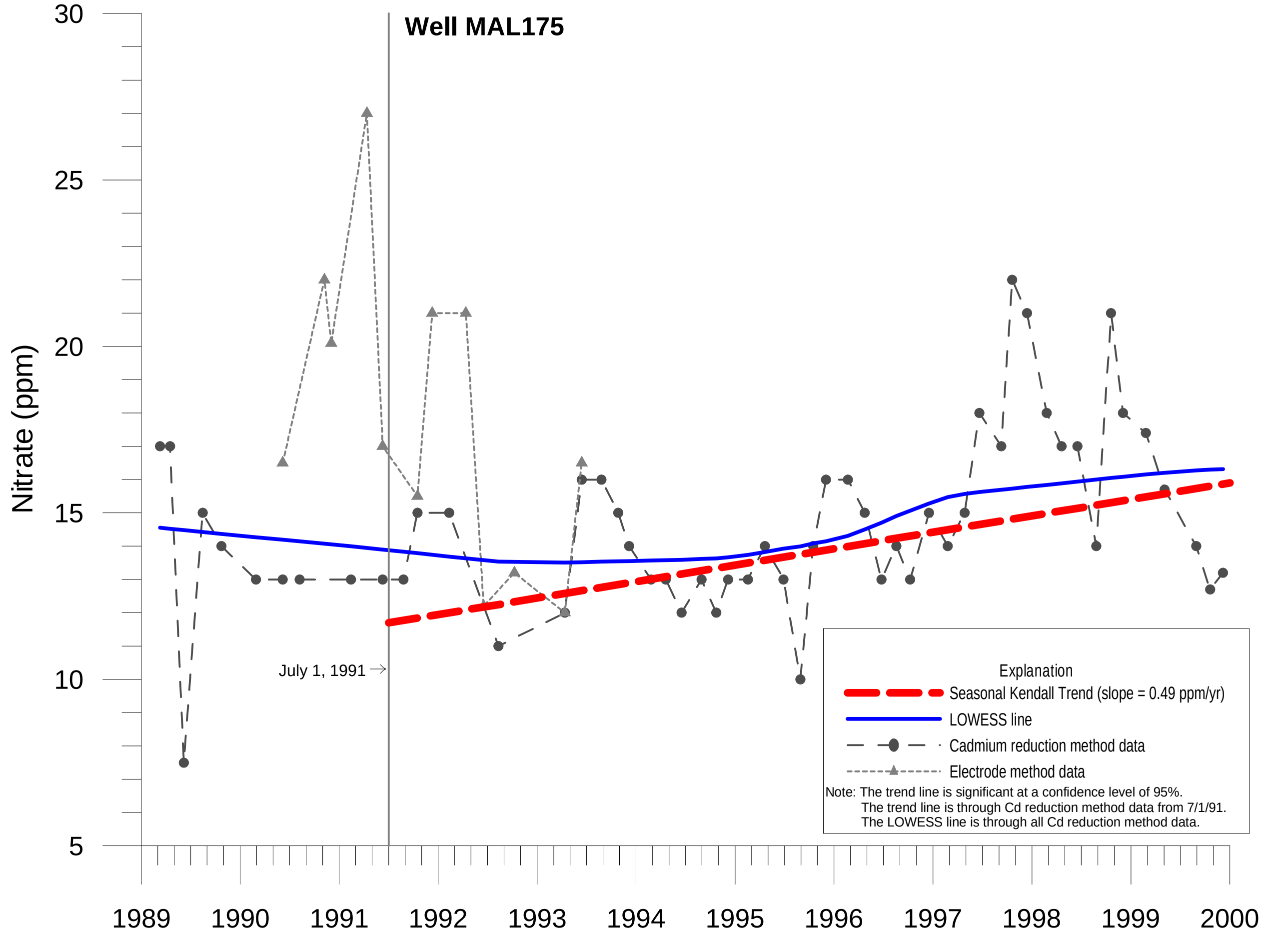

Well MAL152
Explanation
Seasonal Kendall Trend (slope = -8.69 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 95%.
DCPA & Metabolites (ppb)
July 1, 1991
0
50
100
150
200
250
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999

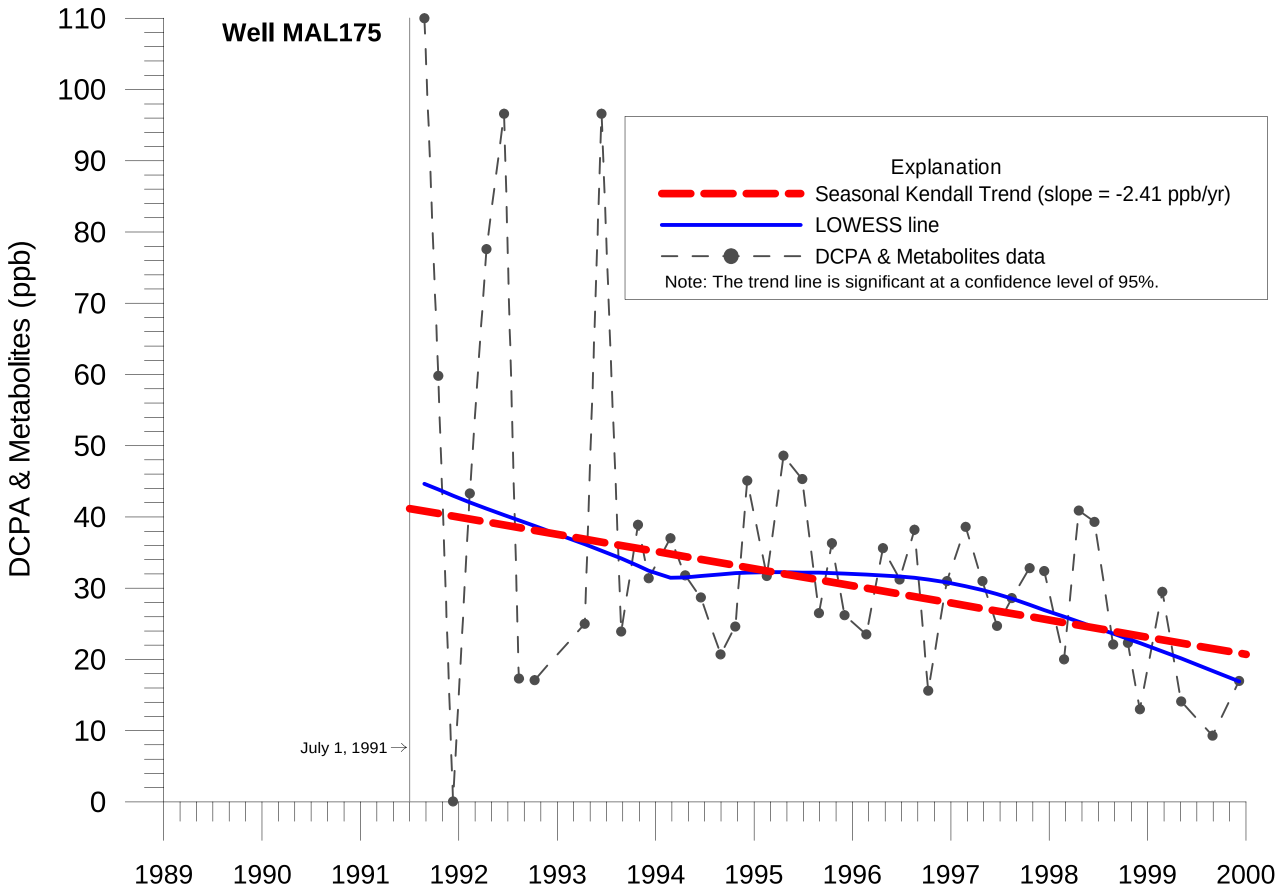

Well MAL164
Explanation
Seasonal Kendall Trend (slope = -0.59 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
0
5
10
15
20
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

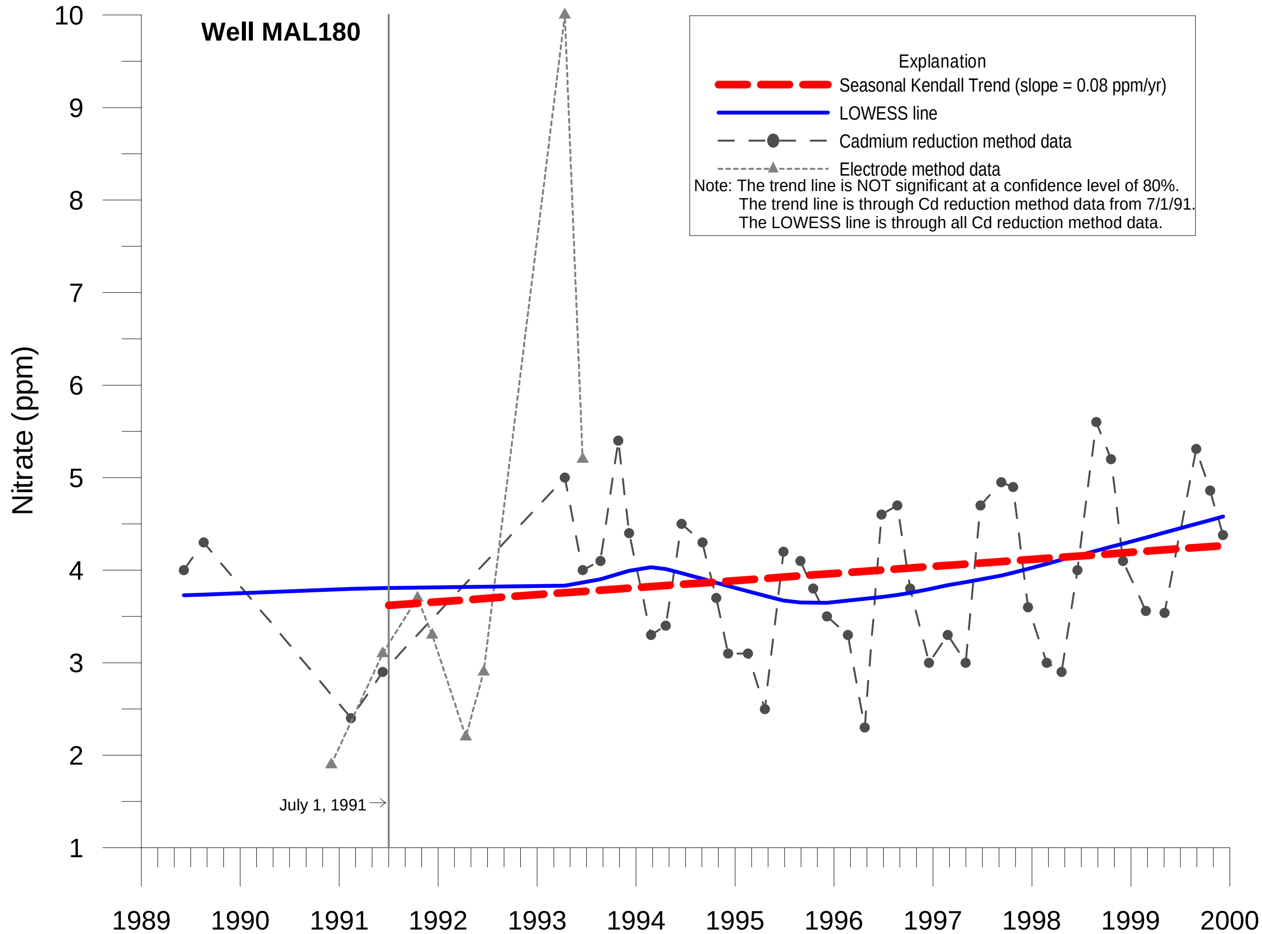

Well MAL164
Explanation
Seasonal Kendall Trend (slope = 0.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991
0.0
0.5
1.0
1.5
2.0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

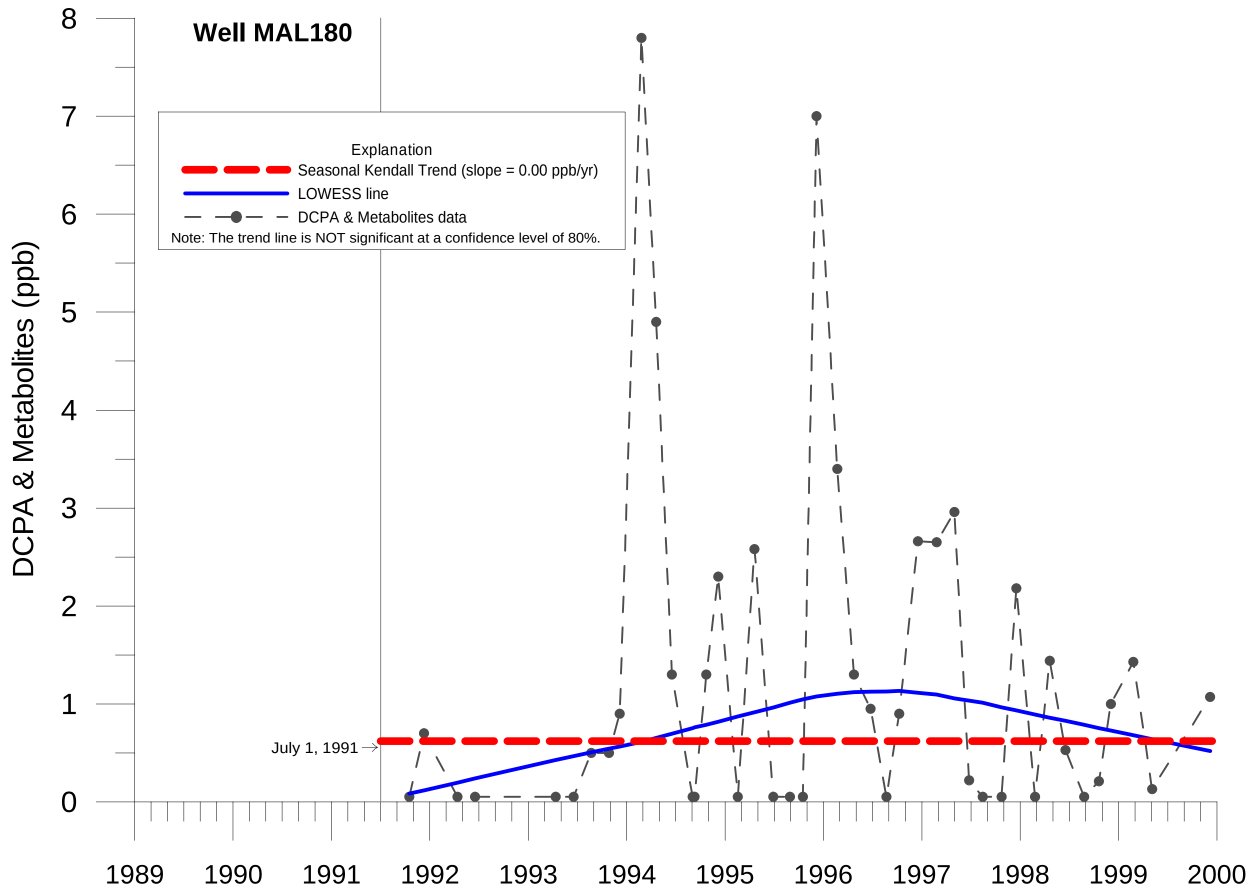

Well MAL172
Explanation
Seasonal Kendall Trend (slope = -0.21 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
0
5
10
15
20
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

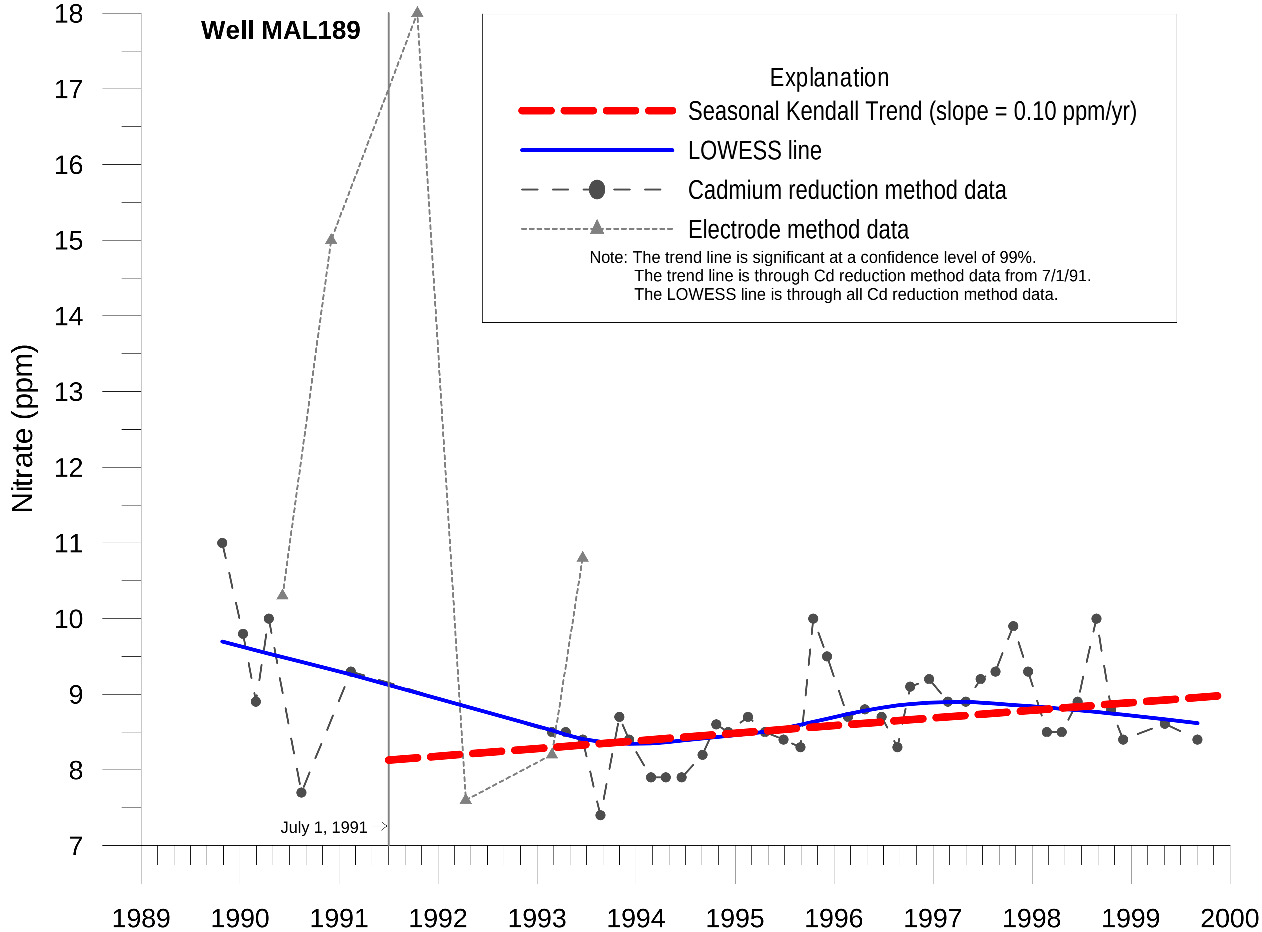

Well MAL172
Explanation
Seasonal Kendall Trend (slope = -0.15 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991
0
5
10
15
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

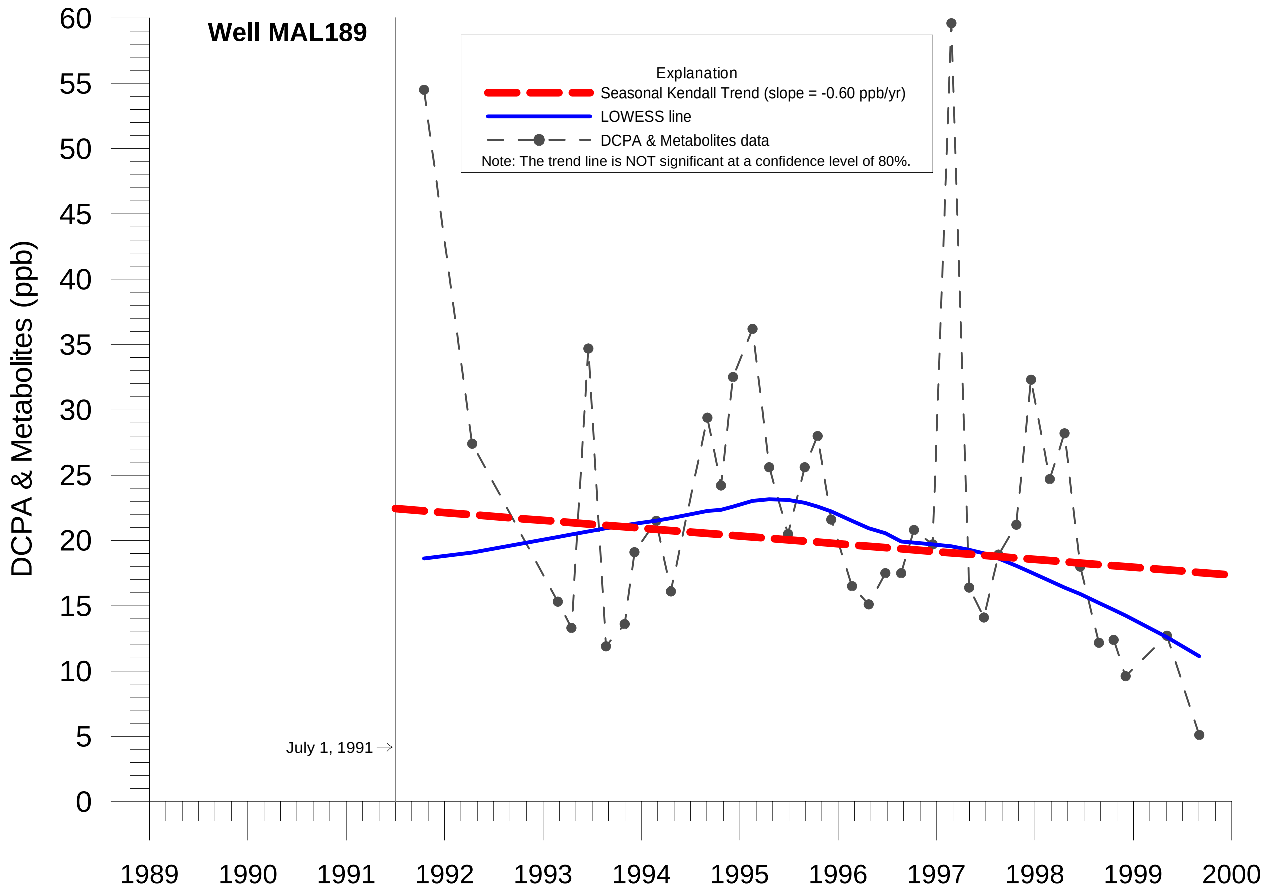

Well MAL175
Nitrate (ppm)
30
25
20
15
10
5
July 1, 1991
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Explanation
Seasonal Kendall Trend (slope = 0.49 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 95%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.

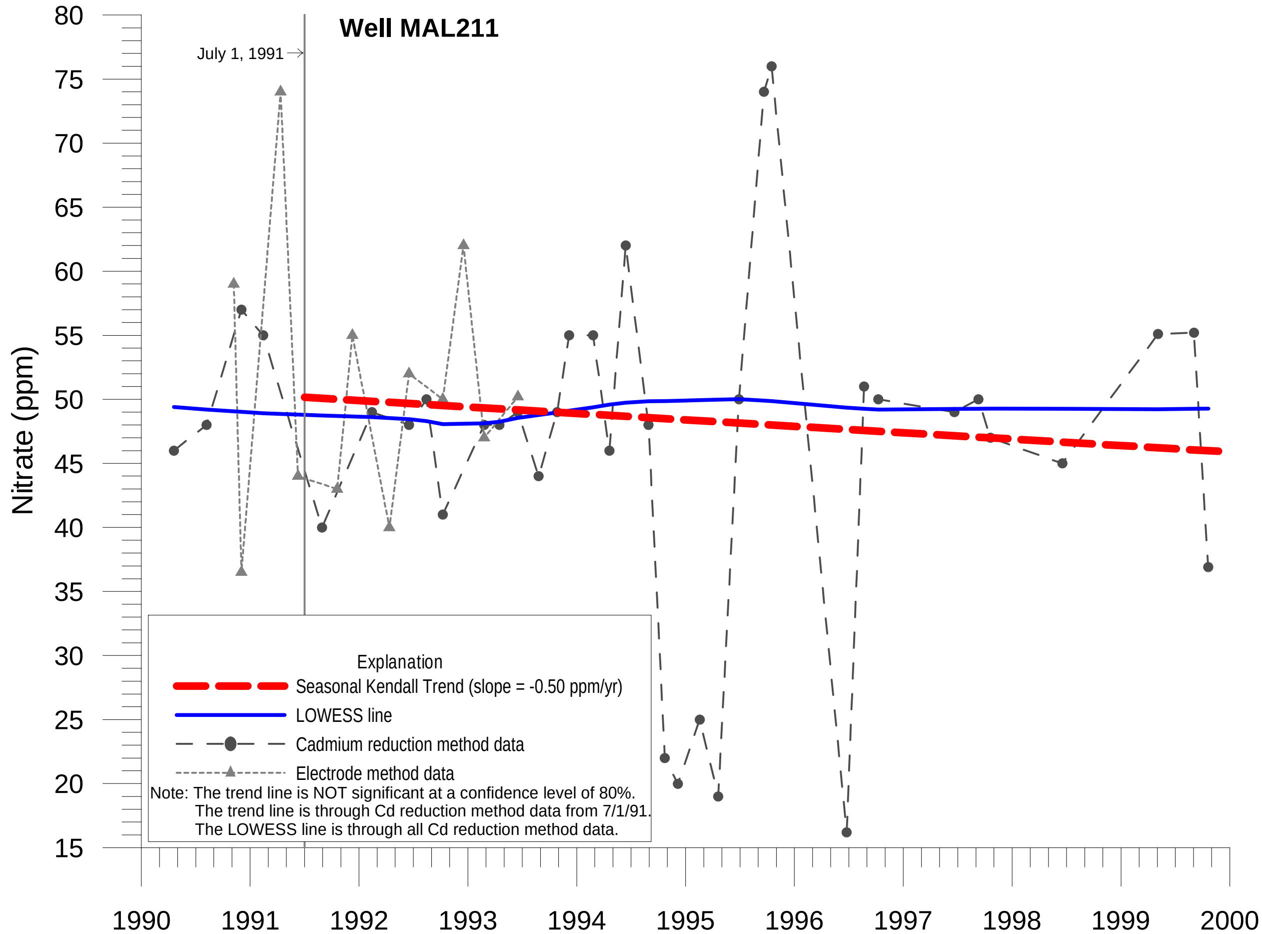

Well MAL175
DCPA & Metabolites (ppb)
110
100
90
80
70
60
50
40
30
20
10
0
July 1, 1991
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Explanation
Seasonal Kendall Trend (slope = -2.41 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 95%.


Well MAL180
Nitrate (ppm)
Explanation
Seasonal Kendall Trend (slope = 0.08 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000

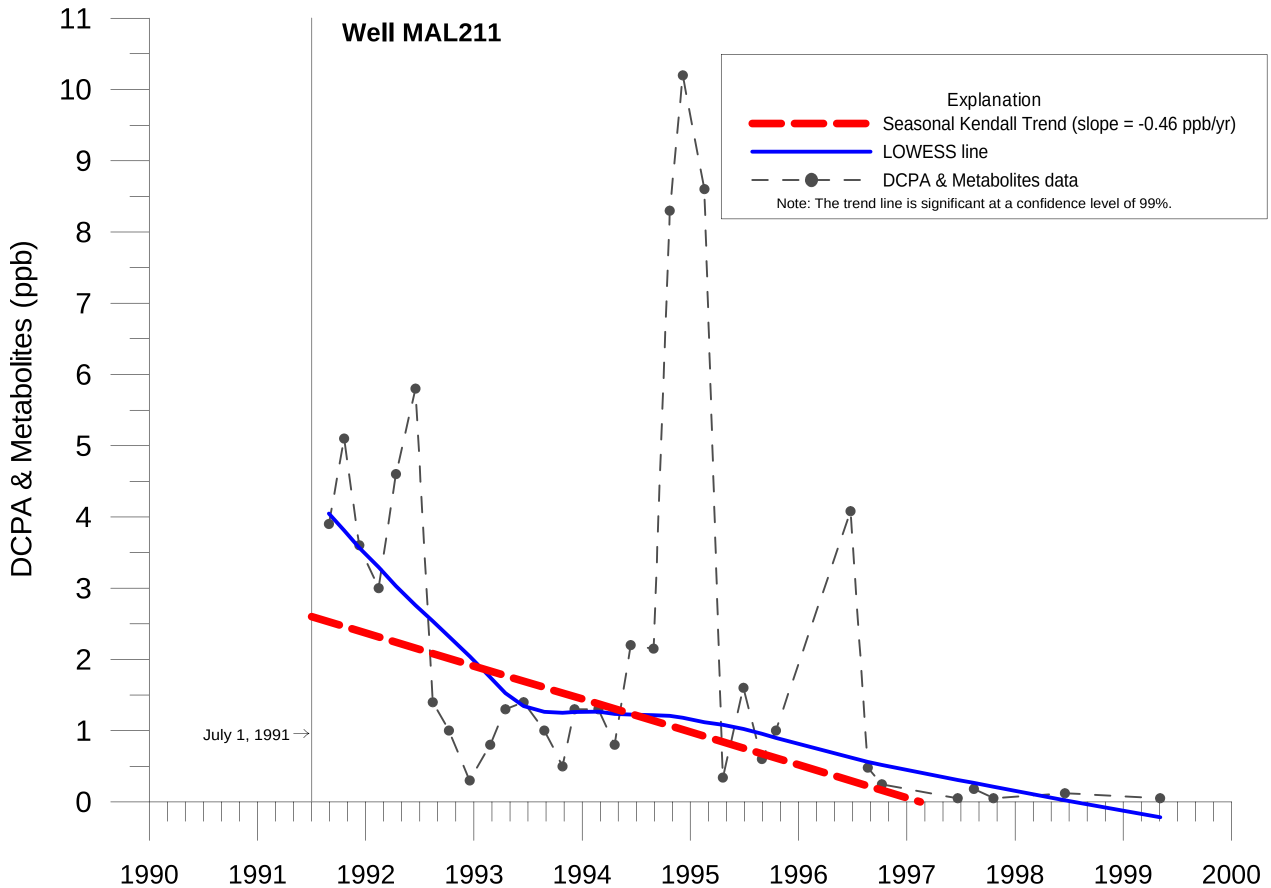

Well MAL180
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = 0.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
July 1, 1991
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000


Well MAL189
Nitrate (ppm)
Explanation
Seasonal Kendall Trend (slope = 0.10 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
18
17
16
15
14
13
12
11
10
9
8
7
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

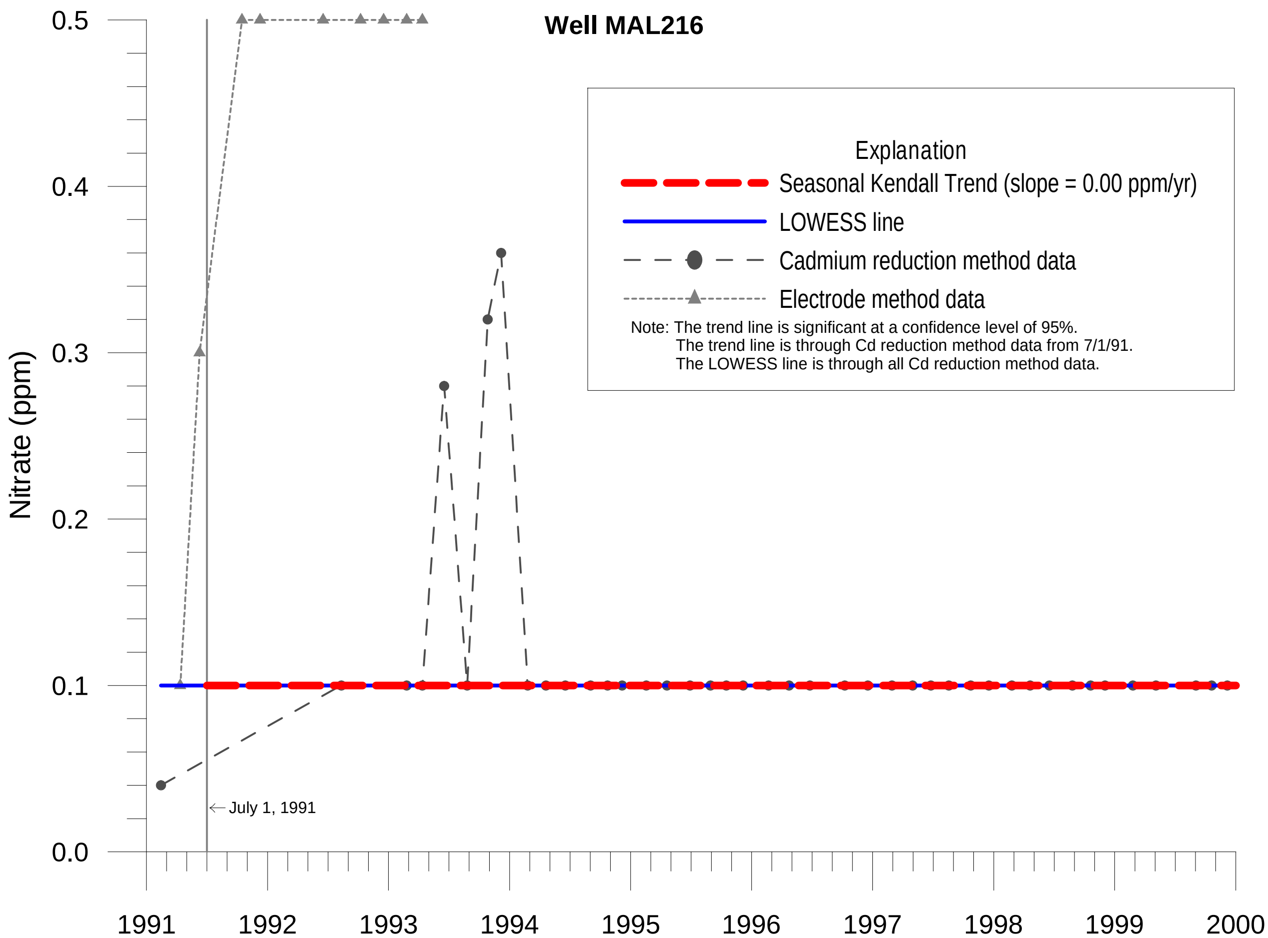

Well MAL189
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = -0.60 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
July 1, 1991
60
55
50
45
40
35
30
25
20
15
10
5
0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

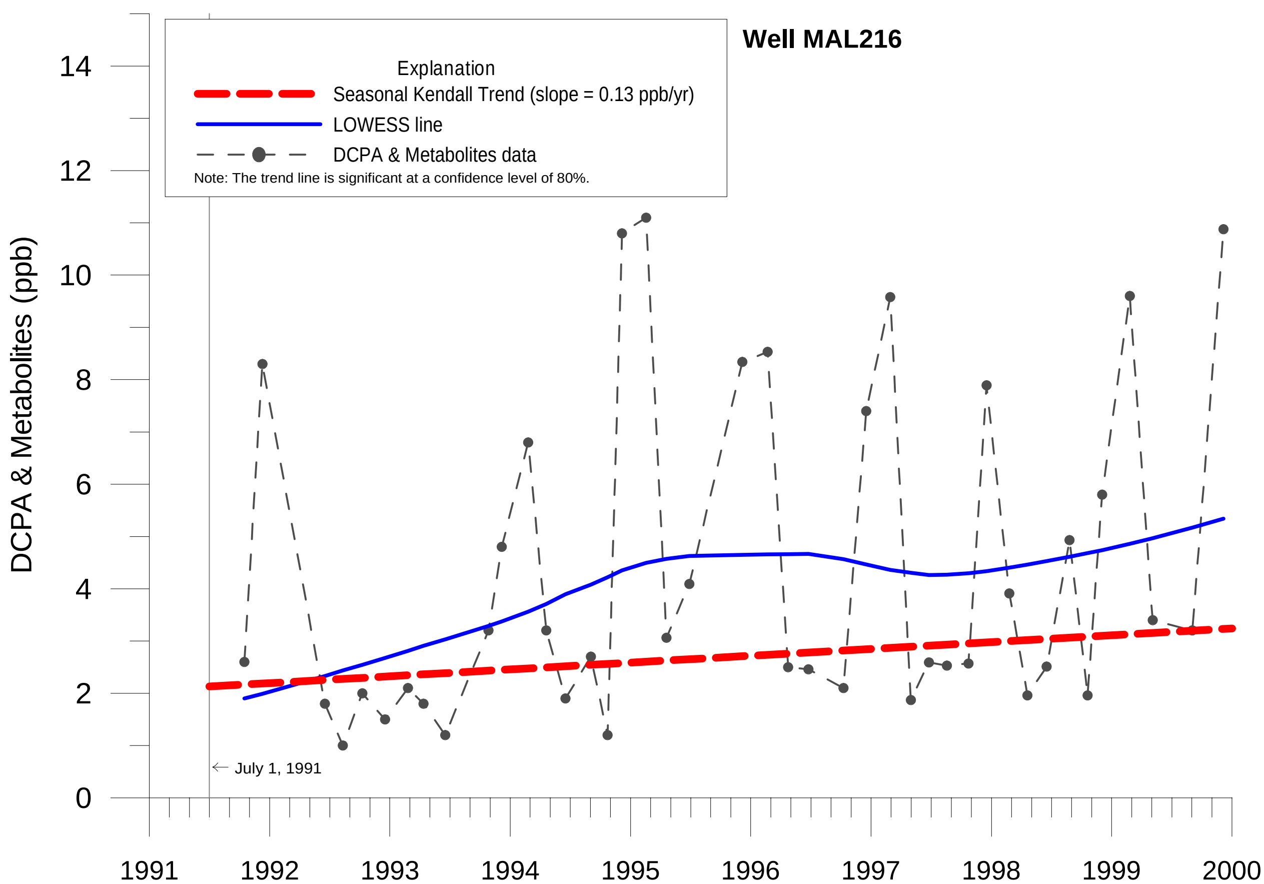


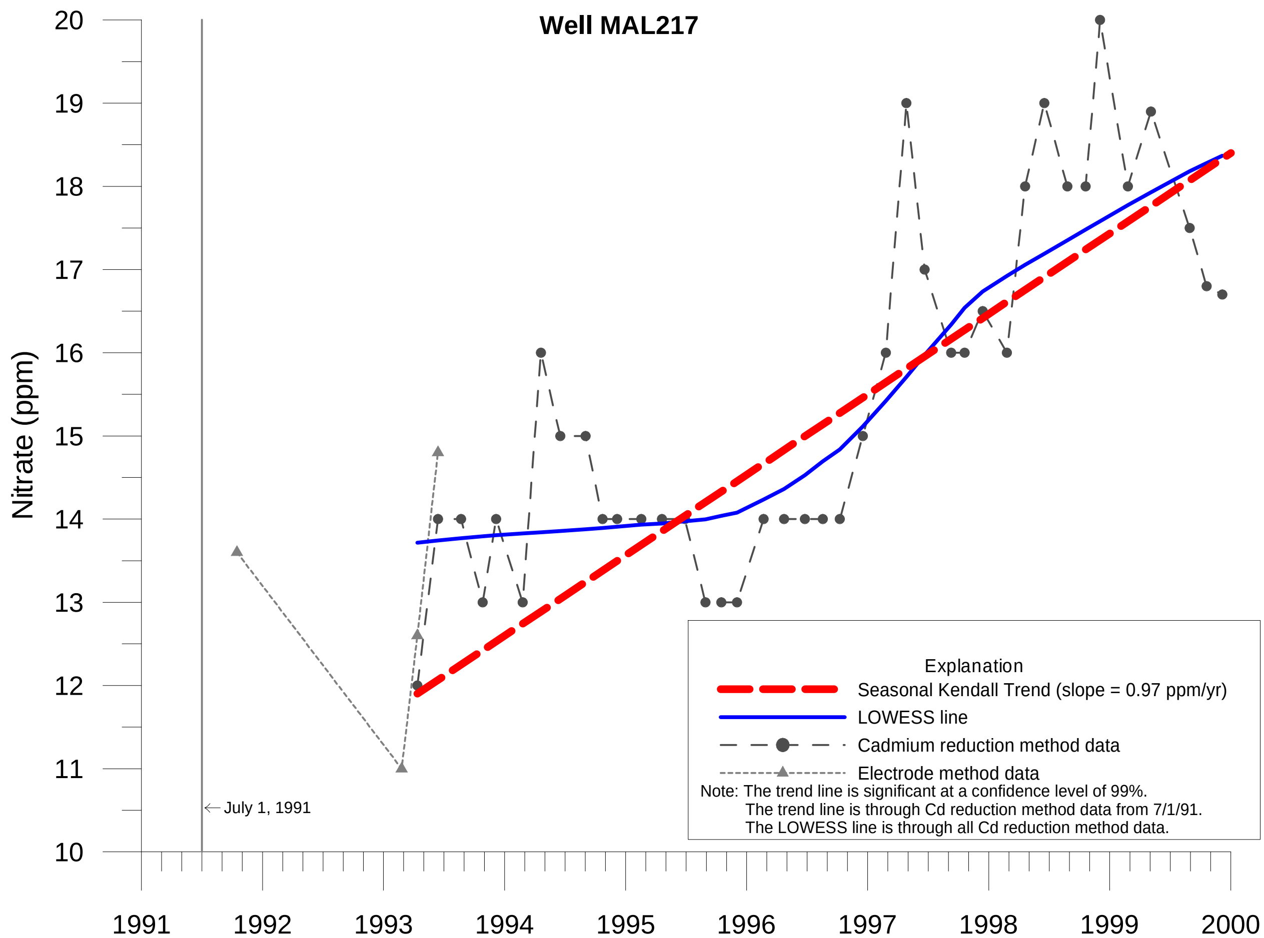
Well MAL211
July 1, 1991
Nitrate (ppm)
Explanation
Seasonal Kendall Trend (slope = -0.50 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
80
75
70
65
60
55
50
45
40
35
30
25
20
15
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000



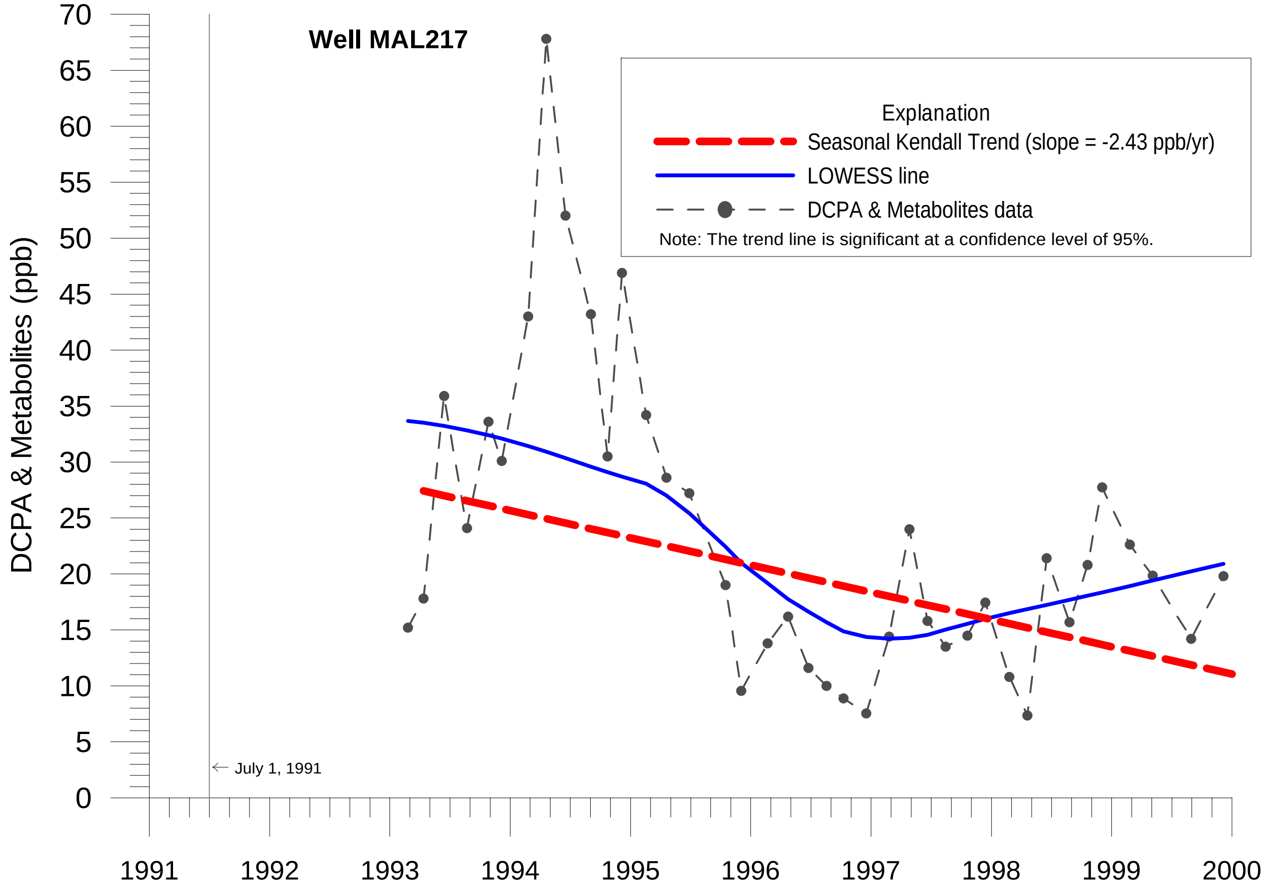
Well MAL211
July 1, 1991
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = -0.46 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
11
10
9
8
7
6
5
4
3
2
1
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Well MAL216
Explanation
Seasonal Kendall Trend (slope = 0.00 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 95%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
0.0
0.1
0.2
0.3
0.4
0.5
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

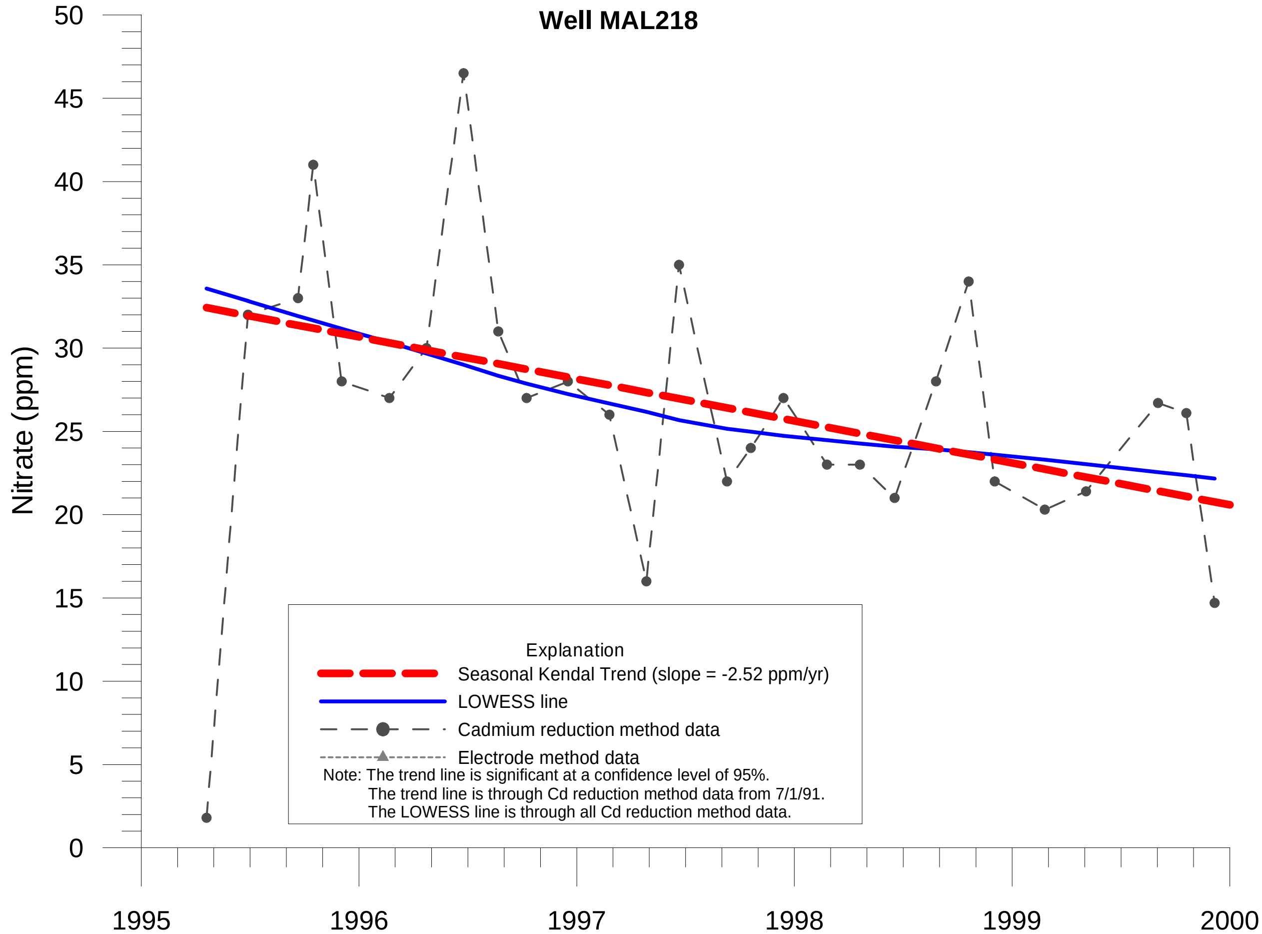

Well MAL216
Explanation
Seasonal Kendall Trend (slope = 0.13 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991
0
2
4
6
8
10
12
14
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

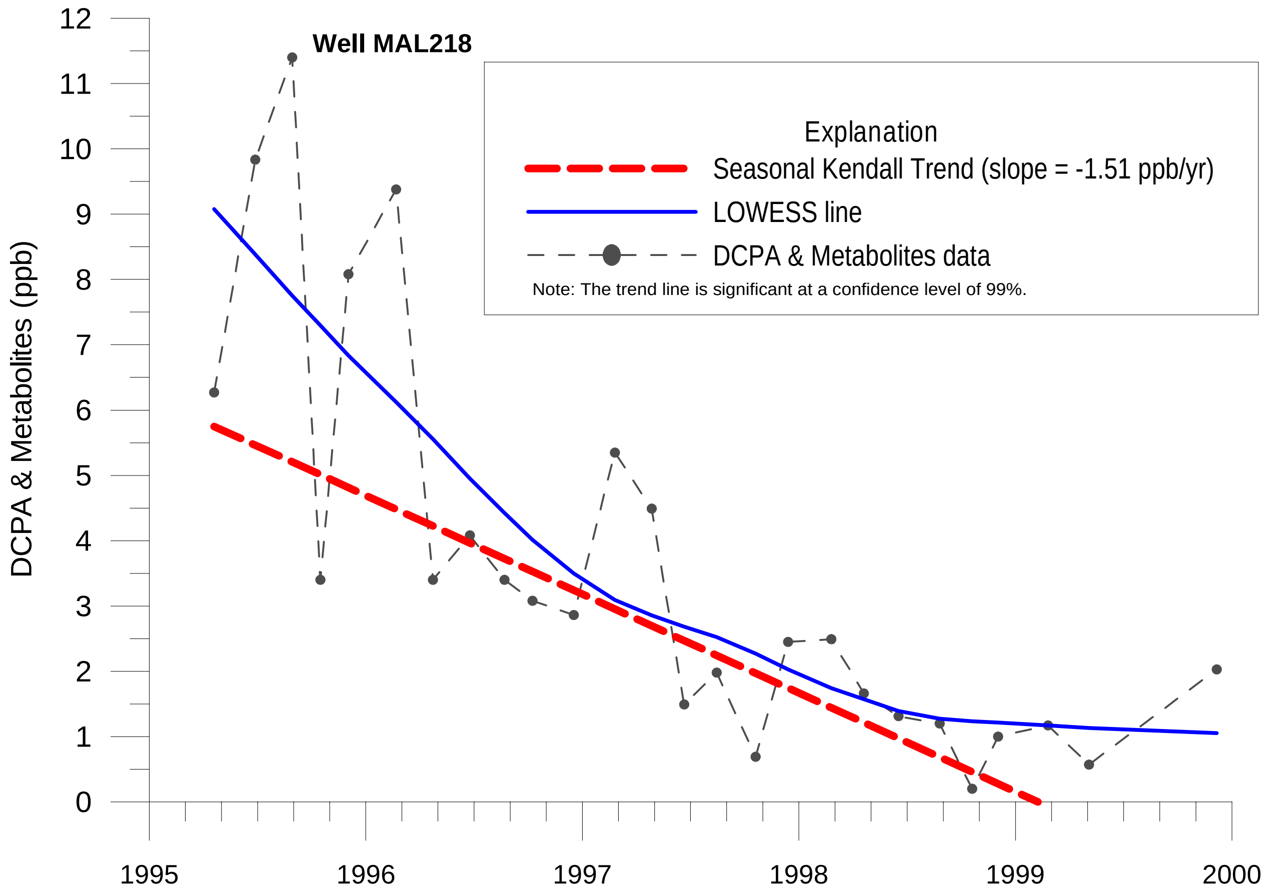


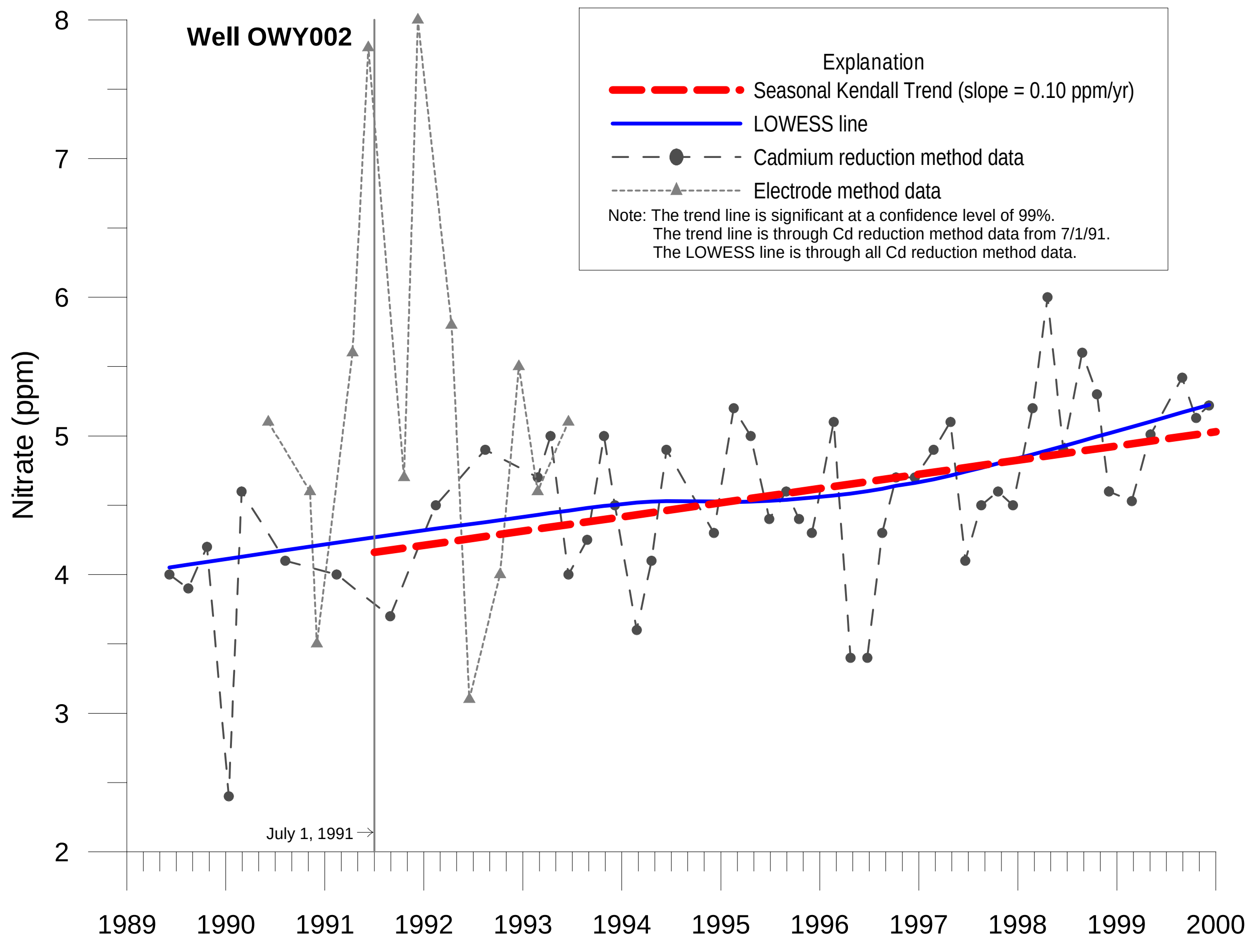
Well MAL217
Nitrate (ppm)
20
19
18
17
16
15
14
13
12
11
10
July 1, 1991
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Explanation
Seasonal Kendall Trend (slope = 0.97 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.



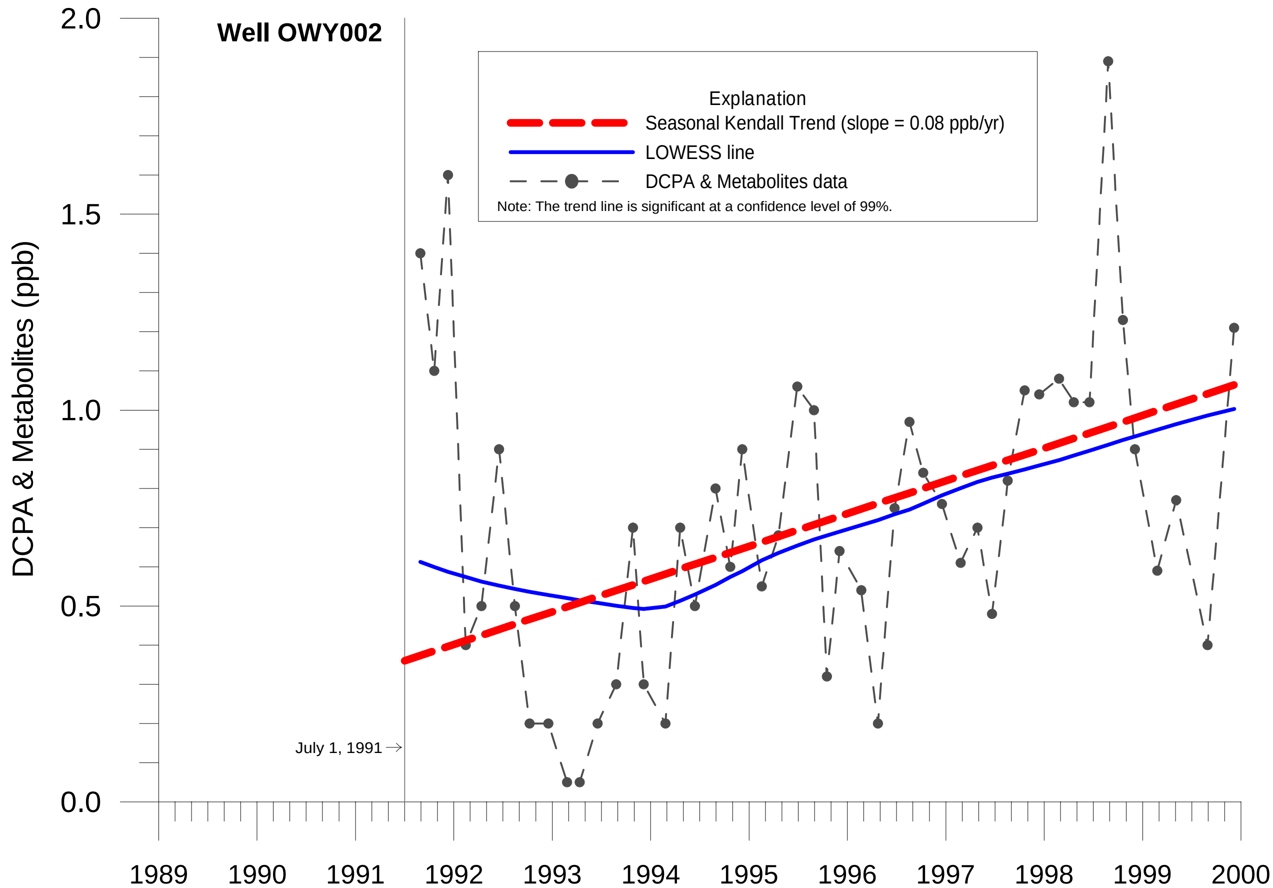
Well MAL217
DCPA & Metabolites (ppb)
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
July 1, 1991
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
Explanation
Seasonal Kendall Trend (slope = -2.43 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 95%.


Well MAL218
Nitrate (ppm)
Explanation
Seasonal Kendal Trend (slope = -2.52 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 95%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
0
5
10
15
20
25
30
35
40
45
50
1995
1996
1997
1998
1999
2000

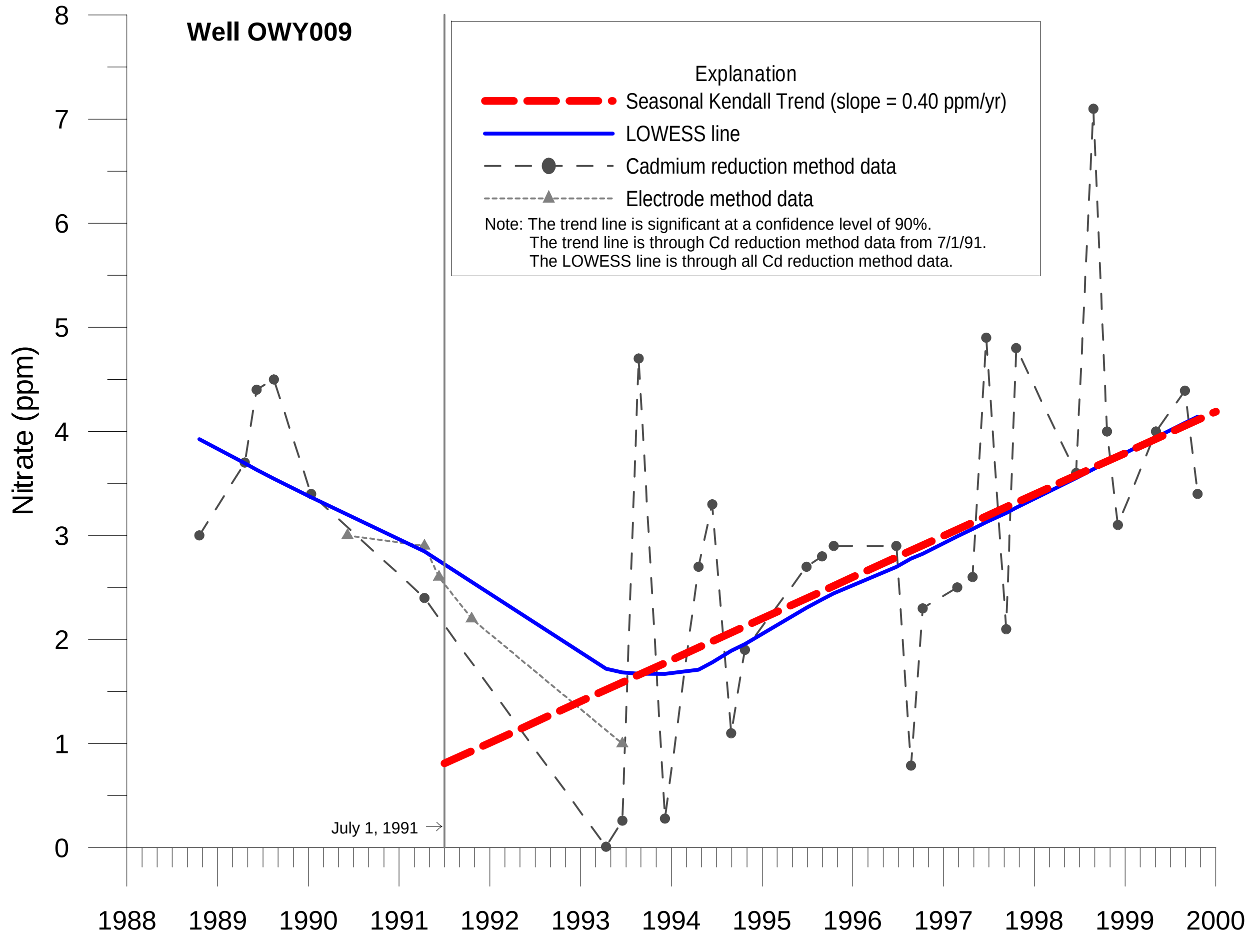

Well MAL218
DCPA & Metabolites (ppb)
Explanation
Seasonal Kendall Trend (slope = -1.51 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
0
1
2
3
4
5
6
7
8
9
10
11
12
1995
1996
1997
1998
1999
2000

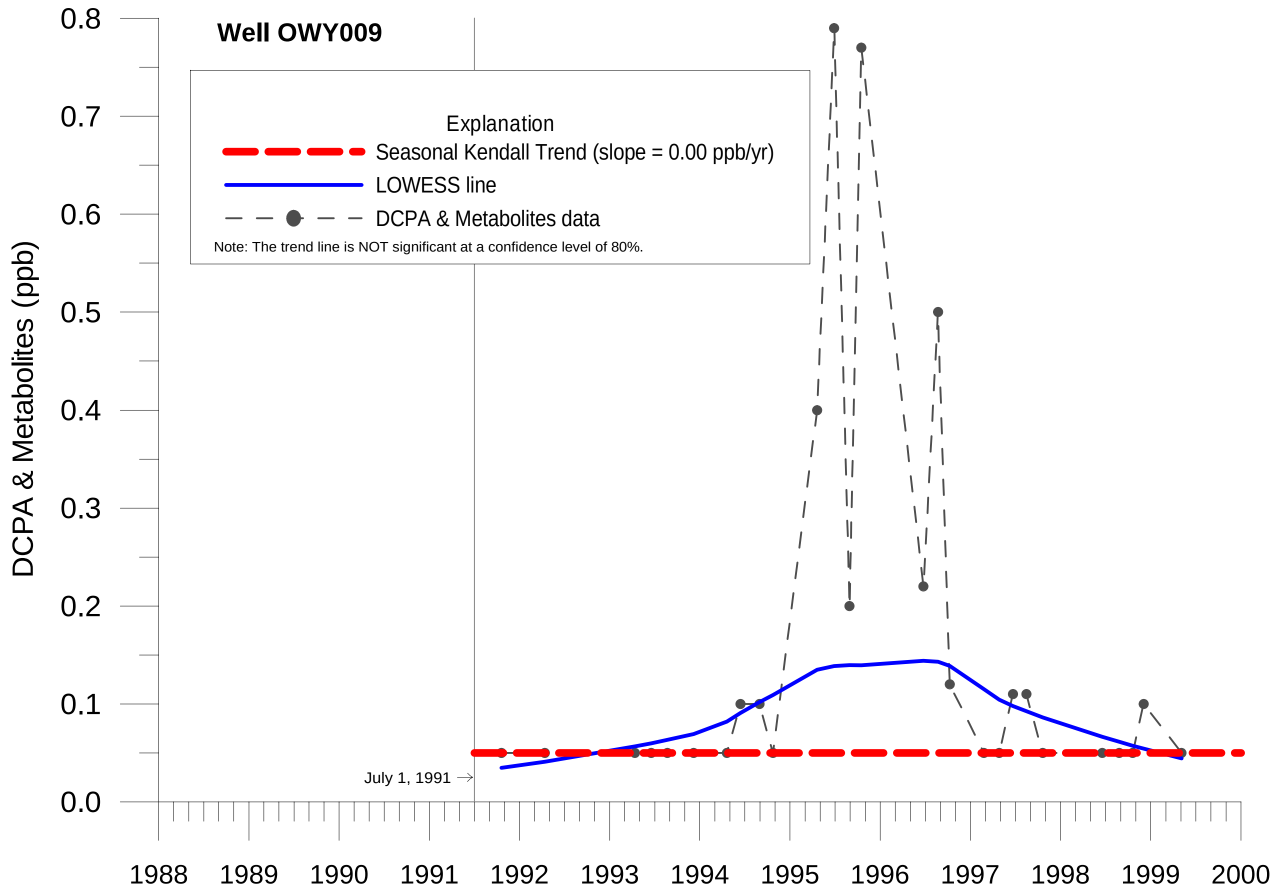


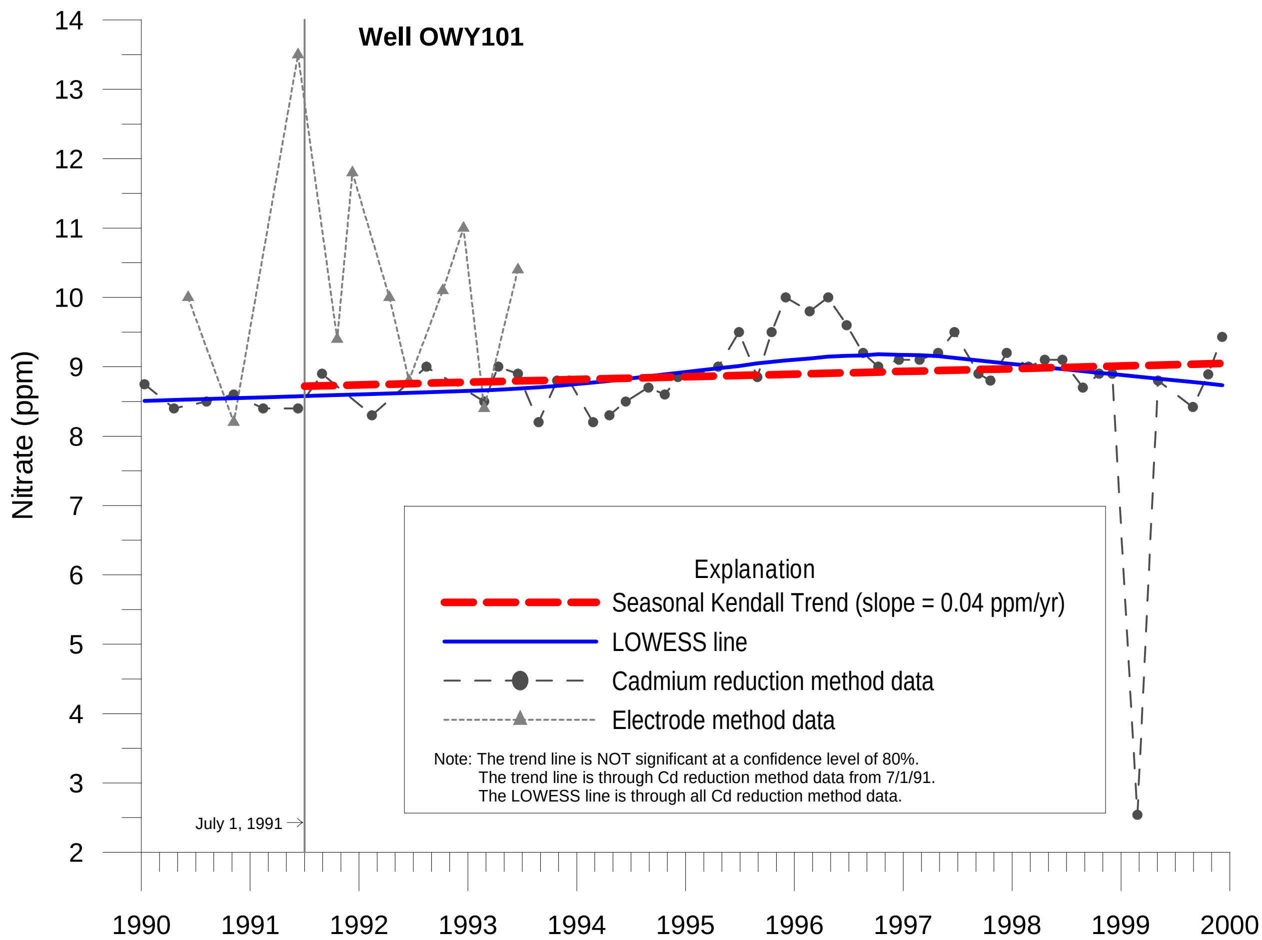
Well OWY002
Explanation
Seasonal Kendall Trend (slope = 0.10 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
July 1, 1991
Nitrate (ppm)
2
3
4
5
6
7
8
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000



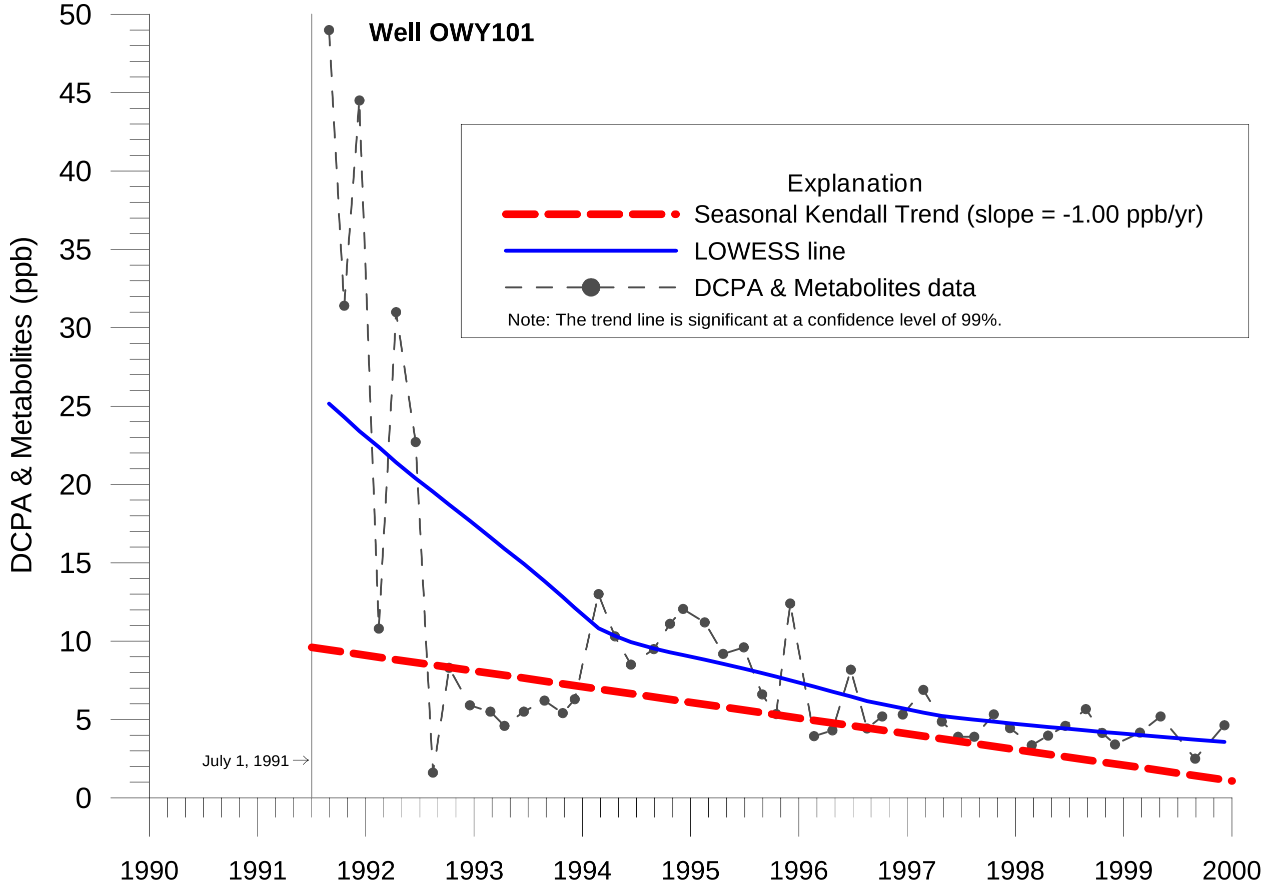
Well OWY002
Explanation
Seasonal Kendall Trend (slope = 0.08 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.
July 1, 1991
DCPA & Metabolites (ppb)
0.0
0.5
1.0
1.5
2.0
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Well OWY009
Explanation
Seasonal Kendall Trend (slope = 0.40 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 90%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
0
1
2
3
4
5
6
7
8
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

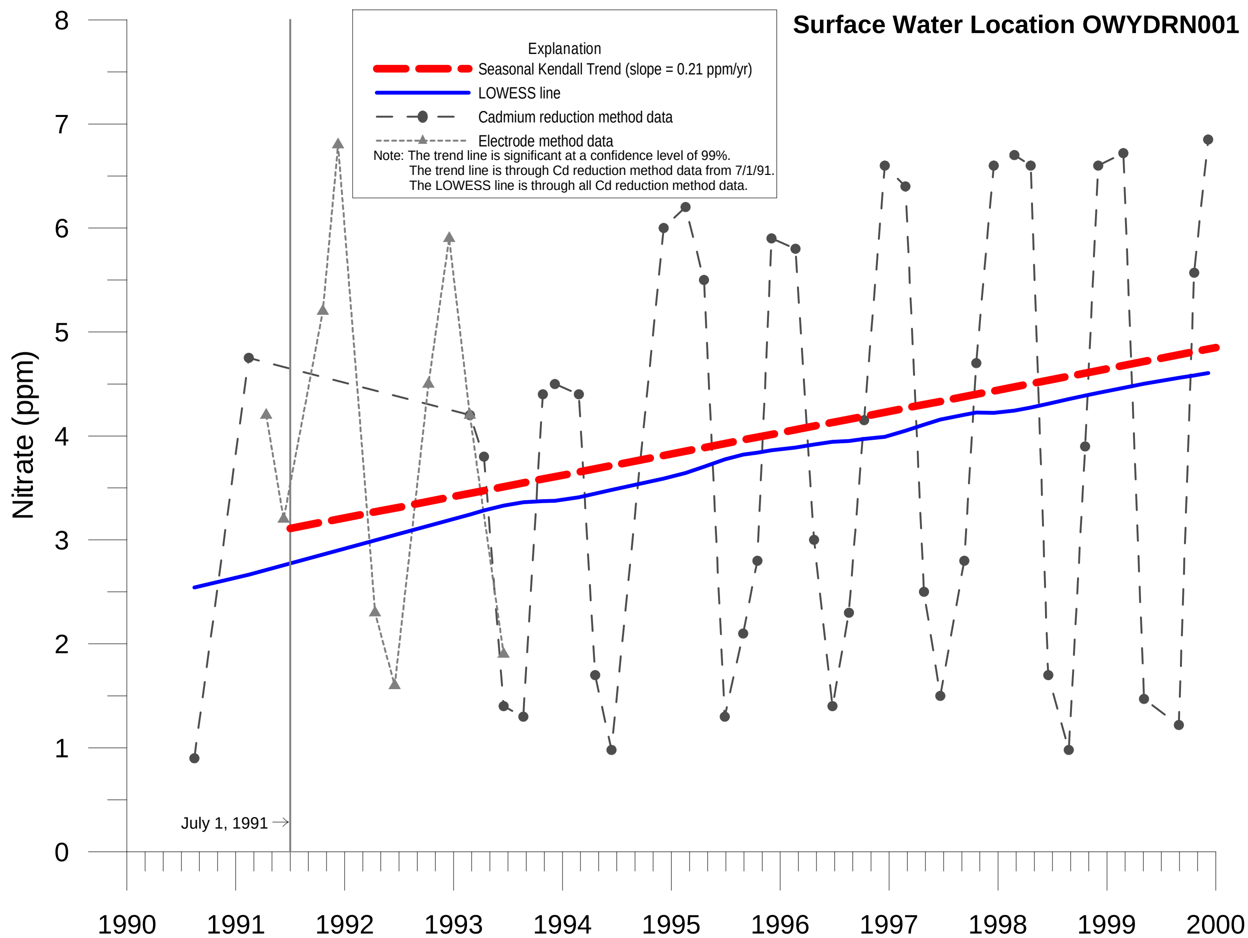

Well OWY009
Explanation
Seasonal Kendall Trend (slope = 0.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

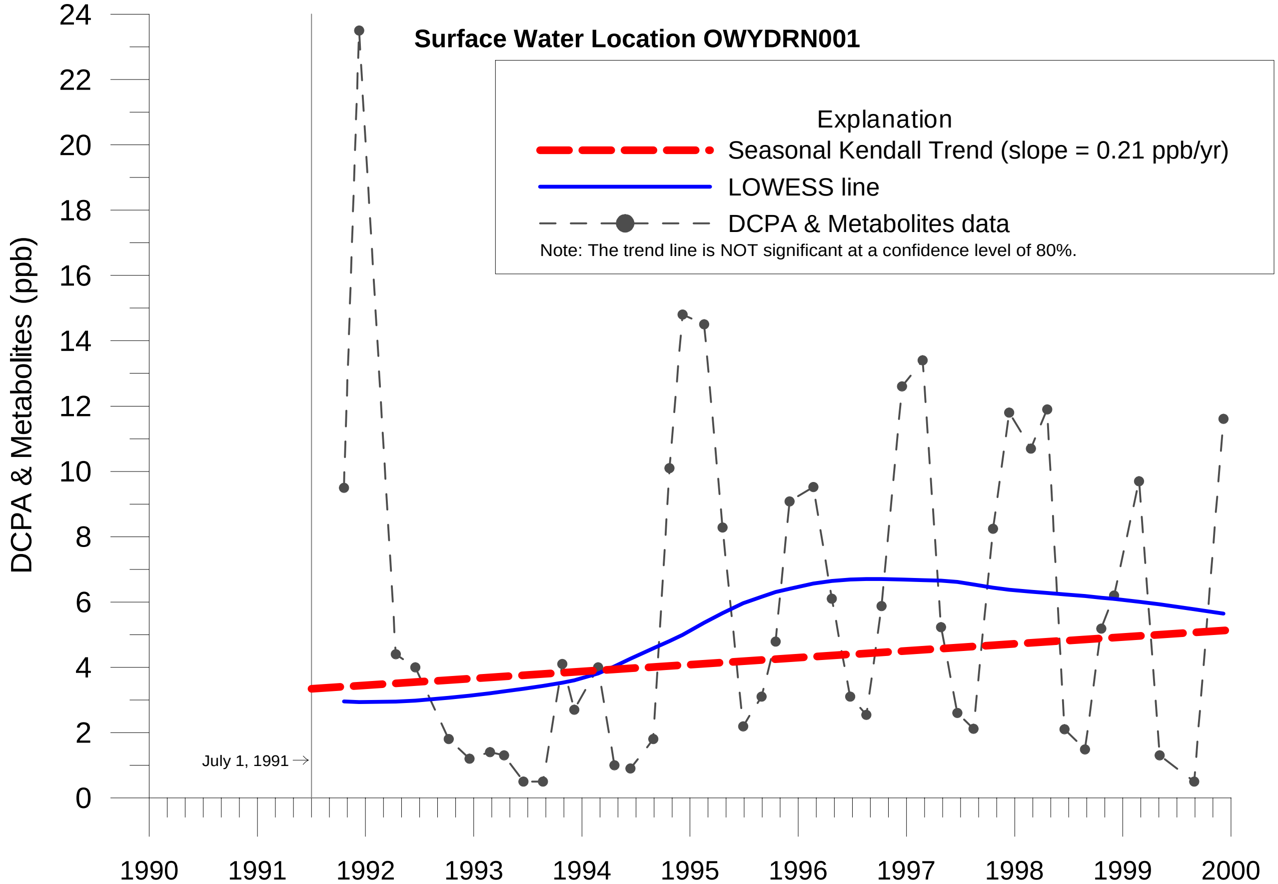


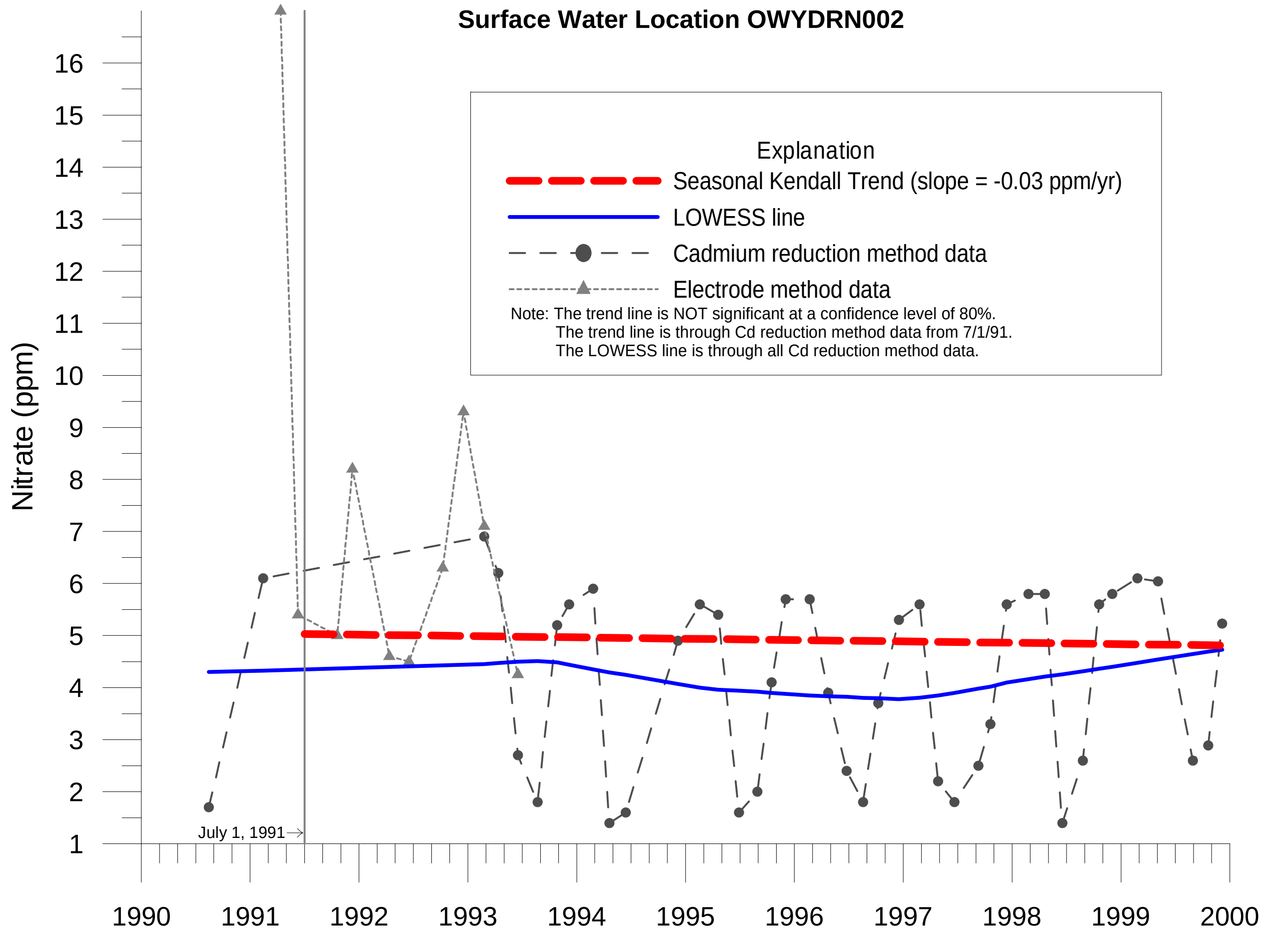
Well OWY101
Nitrate (ppm)
14
13
12
11
10
9
8
7
6
5
4
3
2
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = 0.04 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.



Well OWY101
DCPA & Metabolites (ppb)
50
45
40
35
30
25
20
15
10
5
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
July 1, 1991
Explanation
Seasonal Kendall Trend (slope = -1.00 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is significant at a confidence level of 99%.


Surface Water Location OWYDRN001
Explanation
Seasonal Kendall Trend (slope = 0.21 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is significant at a confidence level of 99%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
0
1
2
3
4
5
6
7
8
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Surface Water Location OWYDRN001
Explanation
Seasonal Kendall Trend (slope = 0.21 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991
0
2
4
6
8
10
12
14
16
18
20
22
24
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000


Surface Water Location OWYDRN002
Explanation
Seasonal Kendall Trend (slope = -0.03 ppm/yr)
LOWESS line
Cadmium reduction method data
Electrode method data
Note: The trend line is NOT significant at a confidence level of 80%.
The trend line is through Cd reduction method data from 7/1/91.
The LOWESS line is through all Cd reduction method data.
Nitrate (ppm)
July 1, 1991
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

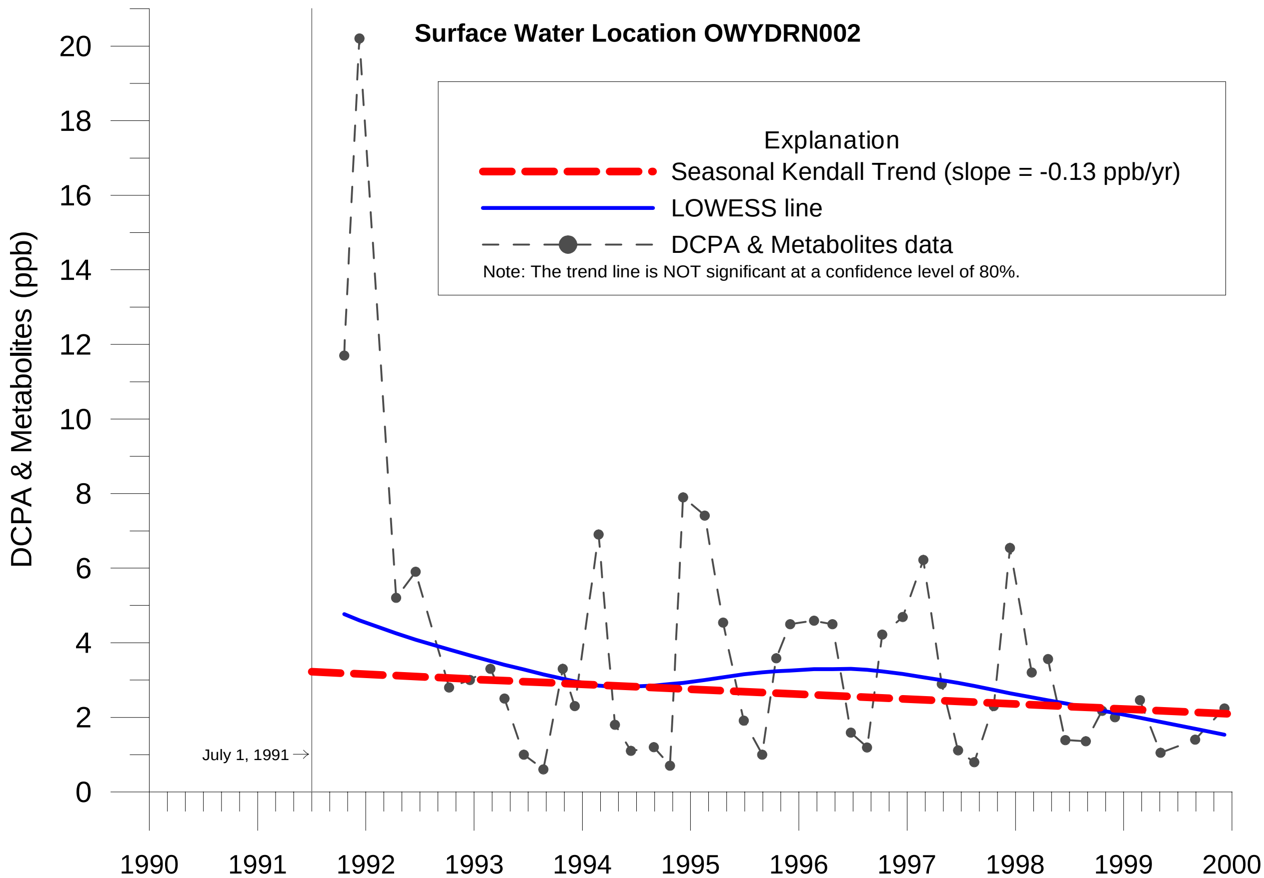
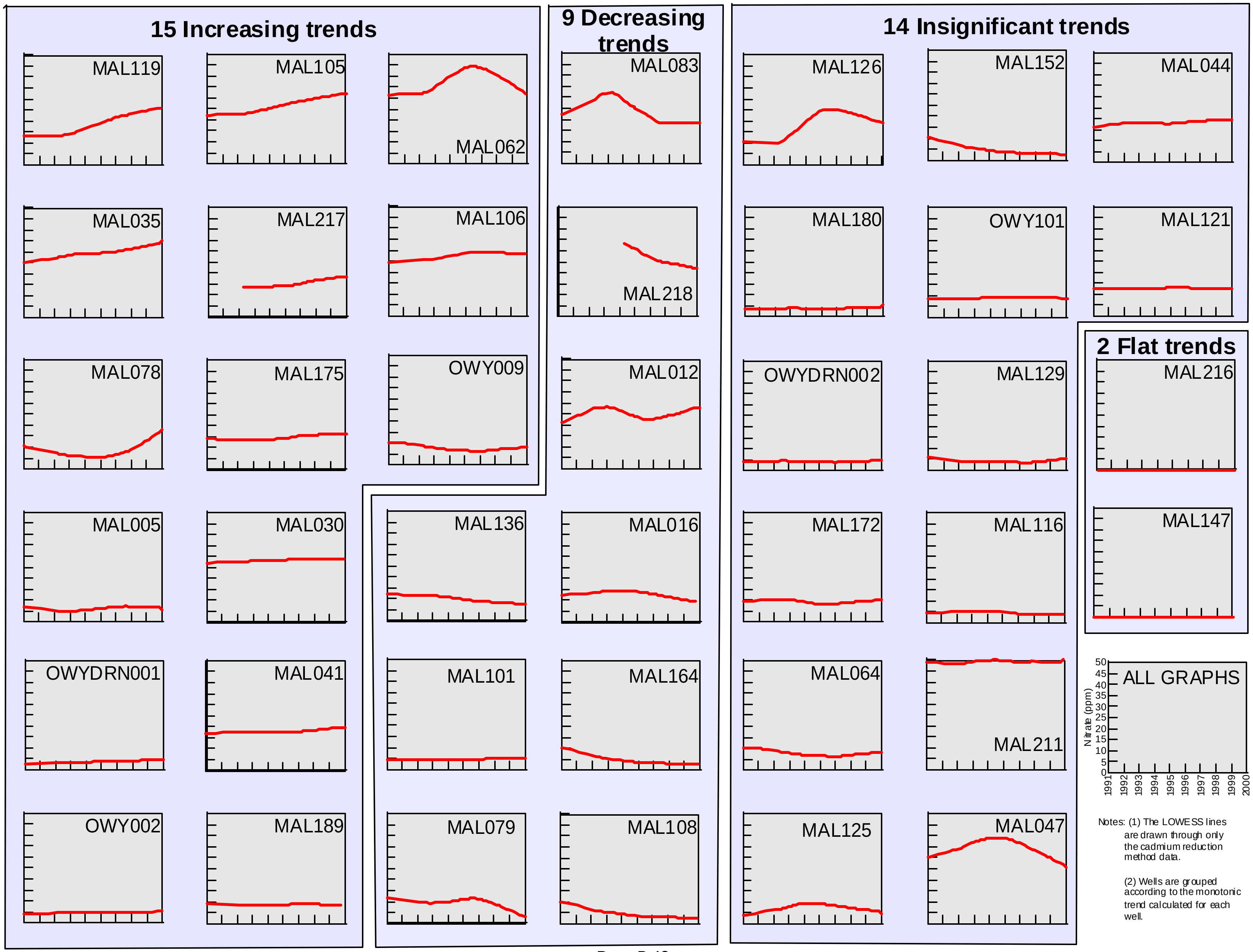

Surface Water Location OWYDRN002
Explanation
Seasonal Kendall Trend (slope = -0.13 ppb/yr)
LOWESS line
DCPA & Metabolites data
Note: The trend line is NOT significant at a confidence level of 80%.
DCPA & Metabolites (ppb)
July 1, 1991
20
18
16
14
12
10
8
6
4
2
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

Table B-1
DEQ and OWRD Well Designations
Northern Malheur County GWMA Trend Analysis Report

DEQ Well ID	OWRD Well ID
MAL005	MALH 626
MAL012	MALH 1188
MAL016	MALH 1606
MAL030	MALH 1496
MAL035	?
MAL041	MALH 1703
MAL044	MALH 1718
MAL047	MALH 1695
MAL062	?
MAL064	MALH 539
MAL078	MALH 1936
MAL079	?
MAL083	MALH 1731
MAL101	MALH 1212
MAL105	MALH 1195
MAL106	?
MAL108	MALH 1927
MAL116	MALH 898
MAL119	MALH 1706
MAL121	MALH 1213
MAL125	MALH 923
MAL126	?
MAL129	MALH 1004
MAL136	MALH 1207
MAL147	MALH 461
MAL152	MALH 469
MAL164	?
MAL172	MALH 190
MAL175	MALH 334
MAL180	MALH 1154
MAL189	MALH 1211
MAL211	?
MAL216	MALH 2526
MAL217	?
MAL218	MALH 3044
OWY002	?
OWY009	MALH 2143
OWY101	MALH 51463

LOWESS Lines Through NMC GWMA Nitrate Data



Appendix C
Previous Trend Analyses

INTRODUCTION

This appendix provides a brief summary of the previous trend analyses and related activities conducted for the Northern Malheur County GWMA. Some trend analyses were included in the December 1991 Action Plan. Other, more informal, trend analyses were also conducted in subsequent years. A summary of each analysis is provided below. Observations and recommendations made in these previous studies were taken into consideration in conducting the current study.

DECEMBER 1991 TREND ANALYSIS

A summary of the trend analysis included in the December 1991 Action Plan is as follows.

Groundwater quality data collected from 1983 to 1990 were examined for trends. This evaluation included correlation between DCPA & metabolites and nitrate, analysis of seasonal trends and an analysis of long-term trends in nitrate and DCPA & metabolites contamination.

Correlation between DCPA & metabolites and Nitrate

A graph presented in Section 6.5 of the Action Plan shows that for a population of 447 sample sets there is a 99.9% probability that a linear relation exists between DCPA & metabolites and nitrate contamination.

Seasonal Trends

All data accumulated between 1983 and 1990 were averaged by quarter and statistical significance evaluated using a student's t-Test. There is a statistically significant increase in DCPA & metabolites concentration during the third quarter (July through September) of each year at the 95% confidence level. Nitrate is significantly higher in both the second (April through June) quarter and the third (July through September) quarter at the 95% confidence level.

When confining the examination to data accumulated at only 15 wells that were consistently sampled from 1983 through 1990, DCPA & metabolites is significantly higher in both the second and third quarters. However, no statistically significant quarterly differences in nitrate concentration can be observed using the same wells.

Long-Term Trends

Long-term trends in DCPA & metabolites concentrations were examined using simple linear regression analysis. When data from 12 wells consistently sampled between June 1983 and August 1990 were examined, a statistically insignificant downward trend was observed.

Long-term trends in nitrate were also examined through linear regression analysis. Data from 15 wells sampled between 1983 and 1990 were evaluated for each well individually. Data from 9 wells show upward trends, 4 wells show downward trends, and there was no trend evident at 2 wells.

Further analysis of trends, using quarterly averaged data from the above 15 wells, shows there is an upward trend in nitrate concentration. Conversely, when quarterly averaged data from all 38 wells are used, there is a downward trend.

Based on the above-discussed analyses, DEQ and the Technical Subcommittee concluded the database was insufficient for statistical analysis.

FEBRUARY 1993 TREND ANALYSIS

A summary of the trend analysis presented in a February 14, 1993 DEQ memorandum is as follows.

For this assessment, given that changes in groundwater quality are usually gradual, efforts were restricted to analyzing selected well network data for monotonic water quality trends.

No attempt was made in this assessment to reduce the effect of outside influence. Therefore, results of this trends assessment should be interpreted with caution.

The general monotonic trending technique applied for this assessment was the Seasonal Kendall Test. A seasonal version of Sen's nonparametric method was used to estimate the magnitude of the trend slope. These nonparametric (distribution-free) statistical tests are most appropriate for many water quality parameters which do not follow a normal (bell-shaped) statistical distribution curve. Frequency histogram plots of Northern Malheur County DCPA & metabolites data more closely fit a log-normal distribution.

For this assessment, a 95% confidence level was used to conclude that a significant trend exists.

The value from the date closest to the middle of each quarter was selected for use in trending analysis. Quarterly data analysis was selected because in most of the data sets there was at least one data point in every quarter from 1989 to 1992.

A previous assessment considered ten wells to have significant nitrate trends at the 95% confidence level. Of these 10 wells, the six listed below had the required data to test for trends in nitrate and DCPA & metabolites:

Well	Nitrate	DCPA & metabolites
MAL012	*Increase; Significant at 95% confidence level*	Increase; Significant 90% confidence level
MAL047	Increase; Significant at 80% confidence level	Decrease; Significant at 90% confidence level
MAL044	*Increase; Significant at 99% confidence level*	Decrease; Not Significant at 80% confidence level
MAL030	Increase; Not Significant at 80% confidence level	Decrease; Not Significant at 80% confidence level
MAL172	Increase; Significant at 80% confidence level	Decrease; Not Significant at 80% confidence level
MAL164	Decrease; Significant at 80% confidence level	Decrease; Not Significant at 80% confidence level

The February 1993 Analysis made the following Recommendations for Future Assessments:

- Identify key indicator wells from each aquifer to be assessed.
- Use the Seasonal Kendall test to assess trends.
- Apply the trend test to a minimum of 5 years of quarterly or bi-monthly data.
- Research the validity of testing wells for global trends using the test developed by van Belle and Hughes (1984). The three aquifers of interest are The Glenns Ferry Formation, the upland gravel aquifer, and the shallow alluvial sand and gravel aquifer.
- Test for seasonal trends where sufficient data are available.

- Perform trend/seasonal Sen slope tests annually on selected wells/aquifers to gauge improvements in groundwater quality
- Perform trends assessment on data gathered after implementation of BMPs.
- Explore the use of other statistical tests to assess groundwater quality improvements. A step-trend test to consider is the Seasonal Wilcoxon-Mann-Whitney. Nonparametric seasonal t-tests may also be of interest.

AUGUST 1996 ACTIVITIES

An August 1, 1996 memorandum from DEQ to the Malheur-Owyhee Watershed Council summarized DEQ's tentative course of action for evaluating the implementation of the Action Plan in 1997. The following is a summary of that memorandum.

DEQ has proposed to do the following:

1. Develop a 5-year trend analysis, based on a yearly average for nitrate and DCPA & metabolites for all wells.
2. Evaluate the nitrate and DCPA & metabolites changes during the past 5 years along several groundwater flow paths from upgradient to downgradient sites.
3. The Department will evaluate the data using the Seasonal Kendall test as stipulated in an amendment to the action plan; however, we will also use several other statistical methods for comparison.
4. The Department will work with the council and different agency staff on the review of the statistical analysis and the adequacy of the well network.
5. The Department will document this portion of the evaluation of the Action Plan review.

The data to be evaluated are from the bimonthly sampling of the well network which DEQ established for tracking nitrate and DCPA & metabolites trends in the groundwater.

1997 TREND ANALYSIS

A summary of the trend analysis conducted 1997 (using data collected from 1990 through 1996) is as follows.

DCPA & metabolites data from 36 wells were analyzed using the Seasonal Kendall technique. Statistically significant increasing trends were identified at 6 wells (17%). Statistically significant decreasing trends were identified at 11 wells (30%). Insignificant trends were identified at 19 wells (53%).

Nitrate data were analyzed using the Seasonal Kendall technique. This analysis was conducted on two data sets: one, which included cadmium reduction method plus electrode method data, and one, which included only cadmium reduction method data. Results are summarized as follows:

Cadmium Reduction Method plus Electrode Method data (37 wells)			Cadmium Reduction Method data only (34 wells)		
Increasing	Decreasing	Insignificant	Increasing	Decreasing	Insignificant
10 wells	11 wells	16 wells	10 wells	8 wells	16 wells
27%	30%	43%	29%	24%	47%

JULY 1999 TREND ANALYSIS

A summary of the trend analysis conducted in July 1999 using the Seasonal Kendall test is as follows.

Of the 38 network wells, 31 have ten years of data. The remaining 7 wells have from 2.25 to nearly 7.5 years of data. For this trending analysis summary to present meaningful information and conclusions, only data from those network wells which yielded statistical confidence levels of 95% or better are used. The factors that influence the data to the point where meaningful statistical conclusions cannot be made with a great deal of certainty include, but are not limited to, local and seasonal variability, field sampling and handling methods, and laboratory analytical methods and techniques.

Nitrate

Only data from 1991 forward are used in the nitrate trending analysis. Of the 38 network wells, 18 yielded nitrate data that display statistical confidence levels of 95% or better. Ten of these 18 wells (56%) exhibited an increasing trend in nitrate levels, while 8 of the 18 wells (44%) showed a decreasing trend.

DCPA & metabolites

Only data from 1991 forward are used in the DCPA & metabolites trending analysis. Of the 38 network wells, 13 wells yielded DCPA & metabolites data that display statistical confidence levels of 95% or better. 3 of the 13 wells (23%) showed an increasing trend. 9 of the wells (69%) showed a decreasing trend, while 1 well (8%) showed no significant change.

Conclusions

Because of the number and variety and spatial distribution of nitrate sources (e.g., golf course application of fertilizer, equipment washing stations, on-site septic systems, agricultural practices of applying nitrogenous fertilizing compounds, and land application of nitrogenous waste products), groundwater contamination trends must be considered on a well-by-well basis.

Despite the increase of land under cultivation utilizing pesticides, the use of BMPs has resulted in distinct improvements in groundwater quality, in terms of reduced DCPA & metabolites contamination.

FEBRUARY 2000 TREND ANALYSIS

Shock et al. (2001) presents a brief discussion of trend analysis results in a paper discussing a range of environmental topics relevant to Malheur County. Data sets were constructed of the arithmetic means of nitrate and DCPA & metabolites values from each sampling event from 1991 through 1998. Linear regression was performed on these data sets. Shock et al. (2001) concluded "Malheur County's highly active program has resulted in downward trends in DCPA residues (i.e., DCPA & metabolites) and an overall downward trend in groundwater nitrate. Rural wells isolated from other nitrogen sources have clearer downward nitrate trends. Nitrate contamination in wells on the urban-rural fringe is more problematic. Downward trends in nitrate in drain water from irrigated fields have occurred.